RESEARCH TO REALITY

4TU.Bouw 2014 – 2017

4TU.Bouw is the collaboration between the built environment related faculties of the four technical universities in the Netherlands: Delft University of Technology, Eindhoven University of Technology, University of Twente and Wageningen University & Research.

Future challenges for the built environment, like scarcity of resources, climate change, accelerated population growth and demographic change, demand for joint strategies and action. 4TU.Bouw aims to promote collaboration between the universities, industrial partners and the government, in order to meet these grand challenges ahead.

This book presents an overview of the four-year period from 2014 to 2017. Around 350 researchers and students from the faculties affiliated with 4TU.bouw, worked with at least 300 experts from other faculties, industries, market parties and governments on a range of collaborative research projects, match-making events, and investigative workshops and conferences. Four years of 4TU.Bouw, led by Scientific Director Ulrich Knaack.

4TU.Bouw
center of excellence for the built environment

9 789463 661041 >

4TU.Bouw
center of excellence for the built environment

TU Delft Delft University of Technology

TU/e Technische Universiteit Eindhoven University of Technology

UNIVERSITY OF TWENTE.

WAGENINGEN UNIVERSITY & RESEARCH

4TU.Bouw 2014 – 2017

Ulrich Knaack Scientific Director, Delft University of Technology

Alexander Schmets Executive Director, Delft University of Technology

Siebe Bakker Curator, bureaubakker

Frank van der Hoeven Ambassador, Delft University of Technology – Architecture and the Built Environment

Erik Schlangen Ambassador, Delft University of Technology – Civil Engineering and Geosciences

Bauke de Vries Ambassador, Eindhoven University of Technology – Built Environment

André Dorée Ambassador (Scientific Director from 2018 onwards), University of Twente – Engineering Technology

Peter Russell dean Delft University of Technology – Architecture and the Built Environment

Bert Geerken dean Delft University of Technology – Civil Engineering and Geosciences

Elphie Nelissen dean Eindhoven University of Technology – Built Environment

Geert Dewulf dean University of Twente – Engineering Technology

Editor: **Siebe Bakker** bureaubakker

Design: **Siebe Bakker, Soscha Montero** bureaubakker

Images: bureaubakker, participating researchers

Infographics**: Dré Kampfraath** creative projects & **Frans Schupp** Frans Schupp Grafisch Ontwerp: pp 56, 62, 66, 70, 78, 82, 96, 108, 112, 116, 120, 123, 124, 130, 140, 146, 150, 156, 164, 172, 176, 180, 182, 186, 192, 200, 202, 204, 208, 212, 214, 216, 218, 220, 226, 228, 234, 270, 271, 274 – 303, 308 – 317, 322, 324 & 326
Ad van der Kouwe – Manifesta: pp 196, 272 & 273

Texts & text edit: bureaubakker, participating researchers

Publisher: TU Delft Open

ISBN 9789463661041

RESEARCH TO REALITY

4TU.Bouw 2014 – 2017

CONTENT

LHP

The 4TU.Bouw Lighthouse Projects program aims for imaginative research projects. Through yearly open calls among the researchers of the 4TU.Bouw faculties, a selection of proposals have each been granted a funding of € 50,000,-. The main criteria for selection are: at least two faculties from 4TU.Bouw are involved, the 'imaginative' nature of the research proposal, and the promise of a tangible result (e.g. prototype) within the project term of one year. The program has been set up as a 'seed money' approach; relatively small funding amounts, fast time-frame, set for 'proof of concept', or 'proof of failure'. A testing ground for extreme and 'out-of-the-box' ideas.

PDENG

4TU.Bouw supports a selection of PDEng programs within their affiliated faculties. A PDEng program is a two-year professional, post-academic program, in which university graduates work in close collaboration with the industry on an urgent and industrially relevant topic.

R2R

The Research to Reality Projects were selected through an open call for pitching research proposals to an audience of potential clients and investors during the Research to Reality Conference in 2016

INTRODUCTION

Most of the more persistent man-made structural assets that surround us in everyday life as well as their reliable structural services are normally taken 'as a law of nature' by the general public. Compared to consumer products the service levels of structural assets are extremely high. Bridges with a structural failure rate comparable to that of normal office printers would be considered completely unacceptable, while a tunnel would never be built if they had a service life expectancy comparable to the most long-lasting functional products such as (certain) washing machines or Hi-Fi-systems. The same holds for all built structures, including houses, public and commercial buildings.

Meanwhile, these structural assets together exceed in financial terms the balance of any global financial institution or the yearly budget of e.g. the Dutch government many times. Thus, the importance and impact of the broad field of science and engineering related to the built environment - which includes architecture, architectural engineering, civil engineering, process management, and policy - is not be underestimated, both economically and socially.

Notwithstanding the evident importance of the Built Environment sector, the public perception of this sector is not that positive, a trend that has been developing in the past few decades. The public perception of the sector often leans towards non-innovative, somewhat clumsy, disorganised and conservative.

It is often forgotten that inventions and innovations from any field of science and engineering are finally applied in the context of the built environment.

Developments with respect to e.g. energy comfort, new building materials, and systems are spectacular. For instance, no other innovation has increased the life expectancy of people as much as the broad application of developments in sanitary engineering. It is even so, that the difference between developed and developing countries can be largely attributed to the quality of public sanitation systems. Apparently, the development of an adequate and efficient sanitation system requires the effective collaboration within the so-called 'Golden Triangle', i.e. stable and facilitating governments, trained people and innovation originating from educational and scientific institutions and energetic application by these innovations by the market.

Moreover, the environmental impact of the 'building sector' is huge, given the enormous usage of raw materials. Together with the energy sector, the building sector is at the forefront of addressing great societal challenges related to sustainability, scarcity, and availability of raw materials as well as the transition towards a circular economic model, based on recycling and upcycling of waste materials and structures.

Another development is the need for true multidisciplinary and cross-disciplinary collaboration on these challenges. Almost every field of science and engineering has found its application in the built environment. Developments within quantum mechanics have led to diverse developments like energy efficient lighting (LED), precise positioning and cutting (laser technologies) and of course to the revolutionary introduction of ICT in the built environment. Developments in (micro-) biology have led to the aforementioned sanitation revolution, whereas new insights into the mathematics of planning and operations research allowed building processes at scales that would have never been possible before.

An effective and multidisciplinary approach faces grand challenges ahead, requiring dedication and collaboration. Therefore, the four technical universities decided to collaborate – amongst others – as 4TU.Bouw Center of Excellence for the Built Environment. The 4TU.Bouw Center of Excellence consists of the faculties of Architecture and Civil Engineering and Geosciences at Delft University of Technology, the Department of the Built Environment at Eindhoven University of Technology, the faculty of Engineering Technology at Twente University and Wageningen University & Research. The overall goal of this 4TU initiative is to promote close collaboration between Dutch universities in order to increase competitiveness in international research and education and to concentrate research and education efforts to improve efficiency and scientific excellence.

Led by scientific director Ulrich Knaack during a four-year period from 2014 till 2017, 4TU.Bouw focused on activating and developing the abovementioned collaborative ambitions. Specifically, by means of three programs, supported with a communication strategy directed towards a broader audience than the academic world alone. The Lighthouse Project initiative that actively pursued imaginary research proposals following a funding setup that resembled an 'angel capital' approach; reasonable 'easy' money for intensive and short-term 'proof of concept' or 'proof of failure' proposals. Not all had to succeed in a traditional way, which was made up by the number of projects and their ambitious goals. Secondly, 4TU.Bouw supported the dedicated PDEng-training program contributing to the future availability of well-trained specialists while bridging the gap between academia and the market. Lastly, there were various collaborations with other knowledge institutes and market branch organisations to collectively inform politicians and policy decisionmakers on the relevance and urgency of built environment research and education in order effectively face the nation-wide social and cultural challenges lying ahead.

CONVERSATIONS ON RESEARCH TO REALITY

with Ulrich Knaack
with Marcel Bilow
with Faidra Oikonomopoulou &
Telesilla Bristogianni
with Léon olde Scholtenhuis
with Rijk Blok
with Hans-Jaap Moes

In a series of conversations Research to Reality was explored. What does it mean for the various participants in the 4TU.Bouw programmes? What can they gain? From the experiences and perceptions of the scientific director, the external start-up expert and various researchers, a range of interpretations, challenges, and chances is shown.

Research to Reality in relation to the market, the industry and the 'built environment' at large.

Research to Reality in relation to the knowledge institutes, research opportunities, and educational programmes.

Research to Reality unveiling the drive and the necessity to collaborate and communicate.

Research to Reality as indicator for understanding cultural gaps, as well as for developing mutual beneficial processes and results.

IN CONVERSATION WITH ULRICH KNAACK

Professor of Design of Construction, Department of Architectural Engineering + Technology, Faculty of Architecture, Delft University of Technology

scientific director 4TU.Bouw 2014 – 1027

What was your idea behind Research to Reality?

The standard Research to Reality explanation is: innovation is not an innovation if it is not available to the market. Research to Reality means you're researching something and that needs to be brought to the market, to the reality. That's the outline of this activity.

As I was joining 4TU.Bouw it was a box which had a budget that could be used to do something for our built environment. We investigate things and identify these things, engineer them, research them and then they have to be brought to the market. The Research to Reality concept is; show what you can do and then show how can you bring this to the market. Which means attracting potential users and potential financials to participate in these research results, to help us to identify the way to get things to the market. So, research is used in our built environment reality.

There are two extreme visions on Research to Reality. From the point of research: I do my research, no matter what, as I always do, being fundamental, and when I have a result, I figure out how to get it to the market. Or, I want to finetune the way I do my research and I organize my research in such a way that is already a given that it will go to the market. Where do you stand?

The politically correct answer is in between, that's obvious. 'Freiheit der Forschung und Lehre' as we say in German, that research is kind of free of direct impact into society, as long as it is research which provides knowledge. And so, fundamental research absolutely okay. But we're dealing with the built environment and that's from my perspective a bit a different situation. We are not into material research fundamentals. We need to know the fundamentals, but our focus is to apply these fundamentals to our research. And that is the same for architecture and for urban design, all these fields are very much focused on the use and function within an environment. In the end, we all built something, make something, change things. It could be a strategy, or a method or a tool. It also could be a product or technology which is applied.

Would you say that built environment research is more demand-driven than supply driven?

Haha, these two forces, that's a clear point. So, you do this academic fundamental research and then try to find where it would work, which I would a call pull action. There is also a push action, in which the market, which are the architects, the engineers, the construction companies, is having certain problems. They ask certain solutions and research identifies these. So, there's no truth in one direction, it is actually both, which allows us to be active.

What is the ambition of Research to Reality? Is it to drive a change in the way people work. Or is it to shape the research agendas.

This has two questions. And the first one is; where do I stand? As scientific director of 4TU.Bouw I have to be global. Within the different faculties, I see this variety of investigation needs. As a person, I am pretty much interested in knowledge to be used in the market.

And then the second question is about Research to Reality and how did we use this entire program of 4TU.Bouw. Of course, it is to influence. For one the political activities are to influence national developments, to identify the right target areas that are important. The other thing is, to help our own environment, our faculties, and staff, to get started, that's where for example the PDEng's come into the picture. This is a good instrument, a direct relationship between a research unit and an industry, where you can identify a certain problem and focus on this. It is not a four-years Ph.D. track, but it is limited in size and time. And then the Lighthouse Projects which I like very much as a product. Researchers have difficulties to apply for research program grants, which get bigger and bigger and bigger. Applications complicated and time-consuming. And in the end, only 10 percent of this research is really used in practice. Which is okay for academic fundamental research, but is not good for the society, because you don't see results being used. The Lighthouse Projects are set up to get a faster application of research. You only need a simple application, a pitch for a research idea. You can compare it to venture capital, if things fail then it's not a disaster. At the same time, it is very fast and the money allows you to experiment. What we evaluated at the end is that each year we had some very good results which ended up in larger calls for larger projects. Which is exactly what the Lighthouse Projects are meant for. It is seed-money. It's like venture capital, helping researchers to get things started. I see national research agencies developing similar products to help to get a faster application of research.

Then, do you see the Research to Reality program more as a match-making instrument?

It's an interaction. An interaction between researchers, Ph.D.'s, post-docs, senior researchers and the younger researchers. But it is also an instrument to involve other areas as the construction industry and the manufacturing industries. Besides them, Research to Reality supports the interest from research agencies. Our program is not only about the supply of products to the market, but more about the interaction between the market and the researcher. We did these events, they partly succeed, and partly did not. We realize how difficult it is to overcome the boundaries of both sides. Both need to understand each other's qualities. And then you're creating. If you do not provide these platforms, it will not happen. So, the more you provide, and the more you're able to get the egoistic interest of the participants, either the industry or the research, the more you'll get them to get these things **done. The organized coincidence of interaction happens. That wat it is about.**

Would you say that the Research to Reality initiative is a reaction to how our universities valorisation centres function?

I have to be fair, the valorisation centre in Delft is actually a good instrument, it really works. However, within the built environment, architecture, and civil engineering, the difficulty to be valued for the impact university research has on the industry. Which is strange because when looking at the car industry, they spend millions and millions, they're so well organized and they're so well structured, and they have this very clear interaction between the industry and the university research. And that's why they always have two extra figures at the end of their research budget. That simple. It's just a lot more interaction. I was thinking a lot about why this is and came to the conclusion that our construction market is too small qua units. That's one that makes it complicated. The other thing is that we are producing products for fifty or a hundred years, that have to be reliable. And that have to be super cheap. These are influences that slow down our innovation potential. Those are the boundaries.

Do you think the way research has been done up until now fits the reality we live in, with a fragmented industry, and such?

What are the real game changers? I really see two. For one the manufacturing. Digital craftsmanship. That's going to change our industry. You see how fast this is developing now, and you see what the downsides are as well. Everybody gets afraid about the qualities of the material, but you also see that it has become cheaper and cheaper and cheaper and that it's simpler to access. So, we will see that impact, we will see this change; craftsmanship 2.0. The other one is the individualization of transport, the self-steering car, which will change our demands on spaces, on how we are going to live and work. That's also going to be an impact. You can predict that we'll use fewer offices, you can predict that traveling between these places that will change. You will not get answers from researchers if they continue doing what they do now. You don't get them from the market either, because they're actually frightened. You need a certain interaction that comes from coincidence, someone jumping in from the side.

How are you going to facilitate this?

The Lighthouse Project program is exactly made for this, to identify researchers that have weird ideas. They will never get a standard research grant because they are too young, too artistic, too much focused on certain things that feel blurry, not-proven technology. It is difficult for an administrative system. It is difficult to explain to a strategic board of a university. They need long-term structures. We say test if it works. And that will generate impact with influence.

IN CONVERSATION WITH MARCEL BILOW

dr. Bucky Lab, instructor Department of Architectural Engineering + Technology, Faculty of Architecture, Delft University of Technology and researcher for Lighthouse Projects 'The LIGHTVAN', 'PD Lab' and 'CAST Formwork System'.

What is your take on Research to Reality. How do you interpret it?

For me, it is trying to combine education and academic programs within our universities with the industry. It is a twofold thing. On the one hand, there is a demand from us, the universities, academics, employees and whole programs to be connected to the industry because we have to know what is going on outside. What is the demand? What are they looking for? What are the real-life problems? On the other hand, the industry needs us in order to go ahead, to think about the future, talking about the next 5 years, 10 years, 20 years plus. There is a mutual benefit from both sides when we are able to collaborate within the industry.

When you talk about needing the industry for real-life problems and to know what the demand is, are you not afraid that research becomes too much a following action?

No, in principle there is always something like a testing facility involved in collaboration with the industry. They have to perform a service, so that is driven by the industry's demand. They need for example a certificate for a product. That is actually how we also make money and are able to do other stuff. On the other side,

there is also a creative part that is integrated within our educational program, that is able to predict future developments in discussion with these industries. Everyone knows we are running out of fuel, fossil fuels, so renewable energies, renewable sources of material, recycling, upcycling, all need to be researched and developed. This is something you can, in this barrier-free environment or universities approach differently than within the industry. The industry needs that input in order to find a direction to go. This could not be done in a way in which the industry dictated us and that is also why we have our freedom. But in good discussion together at the table you are able to perform innovative ideas, discover new markets, and also new solutions for the future.

What is the industry adding to this mix?

Their entire expertise. The experiences that they have done through the years. They are already busy with this. They also have the sense that they sometimes running against a border, not being able to increase or improve the technologies, materials or systems. For instance, we see that within the façade industry that the improvement of the insulation of the window or façade frame transforms from a solid piece of metal into spaces, polyamide, to actually try to get the energy flows cut off better. So, there for you see materials coming in, technology changing, and at a certain point they are running into a barrier. And that barrier can only be broken through if you may think about different materials. Materials which have they may not have seen. For example, glass fiber reinforced plastics. If you are in a company that only uses aluminum, you will never find that, they will never search for that. We as a university have a better overview of the different materials, different technologies available, other offsprings, other markets. We are able to pitch these ideas, bring them to the next level and then the industry might actually take this and improve on that. And then we have our knowledge about past building construction. We have seen materials that come to market that change the entire architecture, that change the way we build. Knowing the past, we are able to judge and categorize, bring new ideas into perspective, see them within the overall universe of how things are connected. Companies that are busy with the projects and the stuff they do right now are not able to see so much into the future nor do they know what already happened in the past.

Do you consider the industry when you work with them as research clients or as partners?

Twofold, sometimes you are asked to solve a problem to answer a specific question. And if we are able to perform that way, there are clients. On the other side we also often collaborate on more future-oriented topics and try to think out of the box, then they become equal as partners. They are as open to new ideas as we are, we may have a bolder 'out-of-the-box way of thinking that helps them. We actually need the industry to create products, on an industrial level, that can be sold in high numbers for low prices. And that is what we as a university, as an academic environment, can't provide. So, we need to learn from their experiences and production techniques. There is a mutual benefit for both sides.

Is it easy to find the right industry partner?

No, the industries are a bit sensitive. Money is scarce, budgets are low, for research projects in particular. We have difficulties starting these conversations. The 4TU projects, the seed money like the Lighthouse Projects in particular, are a very handy thing. You can start with your own team. With a limited number of people, like-minded people, who see the benefit of specific technologies, specific ideas, and concepts. You built on that, produce the first tangible results, like a house or a chair or details of constructions. In order to approach the industry, to show where we are right now, what we are able to do with our own means. Then these people, most likely coming from practice, are able to jump in directly because they can actually take these things, test them and judge them in a more practical way. In a way, they are already used to. If you sit at a table and you try to explain something, with a sketch, it is difficult for them to judge and make a decision. If you have already

something you can put on a table, you can discuss it not only with the CEO of the company but also with the guys that are in technology until the last person within the assembly line. Or with the ones that make the façade on the building site. You can judge these elements, prototypes, on very different levels of professional perspective. That really helps.

Does that also mean that the industry is also open to collaborate on research projects that are not directly solving issues that they have at that moment?

Personally, I can say yes, we have the Buckylab for instance in which we always collaborate with an industrial partner. The power of this course is within the principles of thinking out of the box. We work for example with Ahrend, the Dutch furniture company, on the topic of a comfort zone. How do we actually improve the comfort within the work environment, the desk, at which you spend 8 hours a day? To think about what we can do to improve the comfort of the persons in order to reduce the overall energy consumptions of the entire office building. And at the same time to make it a comfortable environment for each of the employees individually. We are actually looking for the ideas they were not able to predict or design. Due to the fact that they are experts, designers, and also engineers that are sometimes limited by the day to day life within the company dealing with production processes, materials and so on. They always try to reduce the impact of new investments, new materials. They first figure out what they can do in the house, to give a table another edge, colour, or something like that. They don't change it in general, because they need to know what is feasible. Our students are able to create because they are not familiar with the restriction these companies have, totally out-of-the-box concepts. To really freely think what might improve an environment, personal comforts zones for examples. These results can later be translated by the industry to products that they can produce.

Are the students, or the researchers, skilled or open or willing enough to also include the expertise and restrictions the industry brings?

That is for us what we do in the engineering phase, after building a prototype on a one to one scale. In the beginning, we try to neglect that. If you tell them exactly what these companies are able to do now and what the restrictions are, the corset is so tight, you won't be able to think freely. Therefore we need to create an environment in which they are able to think freely. Where mistakes, stupid ideas, naive ideas, open ways that later can be transferred and translated into a structure that will actually work. Therefore freeing the mind, in the beginning, is the best. What we call in the course: failure is an option. You should be able to figure out things, test if it works or not. As a researcher for me 'no' is also a positive answer, if you know for sure that what you have tested doesn't work. Within that, you might find other things that are an improvement or something new. That is the reason why these alchemists invented so many different materials like china, porcelain. They tried to make gold but came up with different outcomes that are still now valuable materials.

You now talked about working with students, how does this work with professional designers, researchers or PhD's?

It is the same, the more educated you become, the more difficult it becomes to think freely. So, at the beginning of projects like that, you have to switch off your brain. Get rid of all you know, and all the restrictions you know, the knowledge you gained. Therefore it is also that we need architects to have dreams, to have demands, crazy ideas. For instance, the glass house in Amsterdam. If the architects didn't think it would be a nice idea to just exchange the brickwork with glass bricks, it would have never been further developed into research figuring out all the problems and making it possible. Within the creative phase, you have to be bold, you have to be imaginary, you have to dream. And get rid of all of your knowledge because otherwise you will get stuck very quickly.

A moment ago you said the Lighthouse Project, you called it seed money, is necessary to set up these collaborations between the university and industry to do this 'creative' stuff. Isn't it strange that you need this extra incentive in order to do so? Is it not the core business to do so?

Unfortunately not. You are totally right, but we don't have the budget to do research projects, test first approached, fiddling, tinkering around. We may be able to create time, but not funding. We often have graduation students who are looking for new ideas, trying to test something. Trying to get one step further, not just talking about it, sketching it, rendering it, doing it all on the computer, but trying to build something. You need money, even if it is pocket money. For a graduation student, 2000 euros worth of material is nearly a no-go. You may want something like a micro research project budget. But there is no such money in our faculties.

Every now and then it happens. Within our Lighthouse Project 'PD LAB' we were able to incorporate 4 graduation projects. They made a huge impact on the entire research project. And at the end, it made the production of this entire house possible. Without the money from the 4TU this would have been impossible. Afterwards, we were able to double the money 'in kind ', labour and material costs of industry partners. But only after we were able to make the first steps and present these at the façade fair in Rotterdam. We could show the potential to the industry in a way they could understand and thus were able and eager to get on board.

If I hear you correctly, the university is doing what they can. The collaboration with the industry is beneficial from many different aspects, which almost seems like an ideal situation already. Is it ideal? How would it get closer to the ideal?

No, it is not ideal. As researchers we have a network, there are symposia, there are databases. And if you are into something you can use these online tools, databases, websites, to find the people in the world who are doing the same stuff. You can go to symposia, you can write them, form teams on an academic level. But that is it. You actually should have databases, websites, persons to go to, for creating the contacts for the researcher and the industry. It would be interesting if we know what the industry is looking for. Normally, on company websites, there is a 'career button', which shows the open positions for functions they are needing right now. But there is never a button for research demands. We already have crazy ideas for ourselves and our students. It would be interesting to see if any of these ideas already are identified by the industry, maybe they are able to join us. We can learn way more from them about the current problems, the way they are struggling right now. We can bring new ideas, perspective and directions. That would be nice.

IN CONVERSATION WITH FAIDRA OIKONOMOPOULOU & TELESILLA BRISTOGIANNI

researchers Department of Architectural Engineering + Technology, Faculty of Architecture, and Department Materials, Mechanics, Management & Design, Faculty of Civil Engineering and Geosciences, Delft University of Technology and researchers for Lighthouse Projects 'Restorative Glass' and 'Re3 Glass'.

Research to Reality, what is that for you?

Research to reality is academic research that doesn't stay hidden in a drawer of a university room. It's research that you apply out there and you make the site a better place.

Is that something special, or is that something that happens all the time?

I don't think that it happens all the time. There is a lot of research that could be applied in reality, but because there is no good communication or good collaboration with the industry it remains undiscovered in a way.

What is a good collaboration?

I think the Crystal House façade is a good example because you had a client with a vision, an architectural office, a glass company, an engineering office, and a construction company, so there were many people from different backgrounds

involved. But all, including the university, had the same goal, which was to realize this completely transparent façade and to make it as beautiful as possible, and also as durable as it could be. And by having everyone coordinated towards the same goal, the collaboration was actually very good. I say that because while we were doing this project there were a lot of people that did not believe in it, but none of them were part of any of the teams that were involved. They were external people. They really believed that we could not make this façade. But everyone who worked on it was passionate about making it happen.

Who are those people who said you couldn't make it, where did they come from? Neighbors, newspapers?

Even people from our faculties. People that stopped us and said: you know what, this is going to break in the first summer. There were people from the industry, also from the glass industry that were very skeptical about it. So, it was not negative criticism, but more like concerns. Like: can you do this, are you sure, how will you make it, there were a lot of doubts.

Can you briefly describe the task, the assignment, the process of the Crystal House?

It really started with one brick and how to bond it in a transparent way, proofing that it is safe. And it ended up with actually being at the construction site for seven months to make it happen. There were also aesthetical requirements: maximum transparency which was set by both the client and the architectural office. That was an equal challenge with the structural performance. Our assignment as a group was to practically materialize this transparent supporting façade.

I think Research to Reality actually has to do with people understanding the value of research. I am sure that the Crystal House could have been built somehow by just stacking bricks in an ugly way in an ugly mortar or so. But they believed in the value of research and how this can make a novelty of beautiful things out there. That's where you see this blending successful. You can see the difference in small details.

What is for you the value of research? You say it so easy and it sounds very nice, but what is it?

If there was no research, we would do things the same way we did them thousands of years ago. Without research, without crazy ideas which no one believes in, people would still be living in caves. And then there is also accidental innovation. I think what drives research is the vision to improve things. It is to improve the technology of airplanes, to create transparent structures, to make a more sustainable world. There is every time a different goal.

But what is research?

Research is also fun, to make a mock-up and breaking it to see if it is going to be a safe structure. It doesn't always mean reading books or making a simulation. Research is when you have a problem or a question, but you do not have the solution. It is the way that you invest to find the solution or solutions.

And you can do that in different ways.

There are different ways of doing research that is why we say there is a background literature research as a start for example. So, the first thing that you do is not reinventing the wheel. You see what has been done and it can be that no one solved the specific problem, but they have solved similar ones. You can use what they have done and then start from there. Basically, by conceiving ideas based on the relevant data that you find, and then you have to validate your own idea. You can do it experimentally, numerically, through surveys, it depends on what field you are in, but you have to somehow validate your results. Or your idea.

And then you take the next step and the next step?

Yes, you take the next step and the next step and, in the end, how you validate your research is either that you are collaborating with an industry and it results in a product, or you publish a journal, so it becomes more distributed in the academic world.

And within this Research to Reality setup, it is about how you get your ideas implemented in reality?

Research, in general, improves something, it improves your quality of life, even if this is looking at a beautiful building where you are going every day. Having a better living environment.

A lot of research that has been done can result in amazing inventions, but they stay in drawers in the university and no one, besides the inventors, knows about it. It is crucial to have good communication skills and also to be able to find a good collaboration with the industry where the goal is the same. Otherwise, you may invent something that is very precious, but no one will find out about it.

I think this is the problem of many scientists: maybe they are excellent in their field, but then they have no way to communicate their idea out there. You need to have multiple skills.

In our case with the Crystal House, it was the other way around. They found us, we didn't have to find them. And I guess it was because of a series of communications actually. Initially, MVRDV went to our professor who is an expert on structural glass and works in a structural engineering company. He suggested our research group at TU Delft for the experimental validation of the novel building system, due to our renown expertise in glass and the very good testing facilities of the university. But what we saw afterward is that because of the popularity of the Crystal House, reflected as well to multiple engineering and architectural awards, we got a lot of exposure as a research group, which actually facilitates communication.

You could say that 'Research to Reality' deals with applied research. Can you place that within the context of the university? Do you think it has a place, or do you think that academic research should be always fundamental?

No. I think academia should have both. There is fundamental research from which you can say that it does not always attract the interest of the industry. But in the end, the reason why you do all this research is that everyone's ultimate goal is to apply it or find an explanation for something. So, you should have both. There is a thin line, there is a balance. You cannot turn the university into an industry. But a collaboration between the two can be fruitful for both sides. I think sometimes it is easier to fund applied research than fundamental research, because then at least a company, or an investor, has interest in it. When it comes to fundamental truth, sometimes people can live without it.

Now you touch the funding, is that the main driver of research? Where the money comes from or the fact that you have money?

Well, sometimes it is important because people need to have a salary, and budget for equipment, materials, and so on.

The biggest problem financially concerns the materials and equipment that you need for research and that is very hard to always cover through a university budget. By collaborating with someone, the industry, who is actually interested in your research, you get as a benefit budget that you can invest. You can invest in the equipment you need to actually validate research. So, the funding is very important, because without funding you may have the best idea but you can't validate it.

How do you make sure that the collaboration and communication in your research projects is going well?

It is not always going well. We learn from our mistakes. Where clients didn't really understand the need for research and they thought: there is a very beautiful mock-up, but we are now going to do it in a cheaper way.

How we do research with companies is, that they normally come to us with a conceptual idea. They want to make something but don't know how. So, we have to find out how. Then they say: you have two months to find something out that works. Of course, in two months you cannot make the perfect idea and validate it. So, we work in different concepts, but we don't have an idea about how many concepts. It can be one super strong idea, it can be five. Then we meet again. We decide together what is the most promising direction. We explain the advantages and disadvantages and then they decide whether they want to proceed with this idea or not. When we start, we ourselves don't know what the solution will be, or if there is only one solution.

I think you could apply Research to Reality in two extremes. One is to do fundamental research completely independent. And later decide how to get those ideas out of the drawer into reality. The other way is to collaborate with industry, reality, from the very start. Which one feels more comfortable for you?

We deal actually with both; the Crystal House was the top-down approach, but for example with the 4TU initiative, we started without industry. That is a bottom up. We have an idea and develop it, and slowly we start to show it to companies and architects. And we try to make it real. This is way more difficult but also creative.

I personally like to start from the bottom up. That is because you have an idea in which you believe yourself. It is something that you generated and started to develop. But it helps to have experience in the top-down approach. Because then you know all the ingredients that can make it successful. And you know you have all the practical experience.

Do you have enough facilities, support, circumstances, to really explore this Research to Reality idea to the fullest?

We have great support from our professors. And this is a very good start. And for the rest, we really have a lot of passion to make things. We don't yet have the best lab. You go to other universities or facilities and then you are very jealous. But we have a passion to start from nothing and then slowly built up. And then you get the pleasure that you make something out of it.

I don't think you find a lot of researchers that have everything in the lab. There is always a "toy" you don't have, and you want to get. We do have good facilities. There are things that we are missing. Things that we like to have or materials that we like to have. But it is not restraining us from continuing our research. And there is also the collaboration with other parties. For example, we can collaborate with research institutes.

Do you collaborate with other universities?

An example is that we are both going to the USA as visiting researchers. The reason is that they have an entire department in casting glass, which is our field of expertise. And they have the facilities and the knowledge that we don't have. But they are from a different field, art, so we will gain a lot of knowledge from them and they will also learn from us. It is beneficial for both.

IN CONVERSATION WITH LÉON OLDE SCHOLTENHUIS

assistant professor Department of Construction Management & Engineering, Faculty of Engineering Technology, University of Twente, and researcher for Lighthouse Projects 'Spying the Underground' and 'ExcaSafeZone'.

You are a researcher and as far as I know, you operate within your research also with 'reality' partners: industry, municipalities, clients. What is your view is on this 'Research to Reality' setup, the collaboration and how it works?

I would argue that we as construction managers and civil engineers live in an applied research field, what we usually do cannot be done without reality. The problems we usually address comes from problems we observe in practice. What we see on construction sites going wrong, or as we look at engineering firms and how their processes could be improved or optimized. The phenomena we like to explore, the concepts we like to develop, or the products we like to develop, all come from practice or have a close relation to it. Also, my personal fascination is observing and looking at practice and how to make that better. Of course, there are technological developments and of course, there are more fundamental scientific concepts from other domains. Usually, we adopt them, borrow them and use them as a tool to make construction more mature. So, what we do as researchers in understanding and designing things for practice should be closely intertwined with that.

Does that mean that in your research you follow the need of the industry, or are you also able to identify potential and take a lead?

Although you would want people from industry to say, 'this is where we want to go', sometimes the partners from the industry themselves don't know the existence of some technologies or concepts that we know, because we read literature or go to scientific conferences. So, I think one of our duties is to inform them about what is happening. For example, we are working on the use of sensors in infrastructure. People from municipalities, provinces, and governments, don't all know what we can do with sensors and infrastructures. And from our point of view, we don't know what information they need. It is important to bring that closer to each other. What technology can do and what people in practice need. Sometimes there is a need for some kind of showcase, or meeting, like the Research to Reality type of assemblies, conferences.

Do you organise that kind of meetings? A kind of information exchange, is that part of your schedule or your workload?

What I do is visiting companies. Once in a while, they just ask me to for a talk on issues they are dealing with, mostly in the field of subsurface or inner-city construction. And also, we organize industry symposia. I think we should do that to inform them about what we invent, or what we are thinking of. So, if I look back at one of our Lighthouse Project 'Spying the Underground', developing an augmented reality application, a more applied approach could be: how can we use virtual reality and augmented reality to support maintenance in pipeline construction? A more fundamental one could be: what kind of tools do we need? Or, how do you generate the visualizations more optimal? How should the data models look like? That would provide both a chance for the industry to see what they can do with what we develop, and we can think more about the technical aspects.

What did you do?

In that project we collaborated with the municipality of Rotterdam and a virtual reality company: Recognize. They have a lot of utility data for underground pipelines and cables. Their problem was the way they locate pipelines in the field based on the maps they have. We actually perceived it not so much as a problem, but it there was room for optimisation. Nowadays they go to the field with a drawing or an iPad or something. They have to visually identify cues on the map. If you look at the cues on the map, they could more or less align with the real-life situation. We thought why don't we use virtual models like the compass and the tablet to visualize the cables on top of the camera image of the reality. We were thinking from an applied field, how could such a technology help. A more fundamental question was: what do we need to visualize in augmented reality and can we also visualize buffers of certainties? How sure are we that the pipe is there?

So, you say that there is not so much a split between fundamental and applied research. It is blended into one?

We are not physics scientist, not so much 'lab rats'. The construction site is our lab, the practice. What we study is always something that interferes with the practice. So, what we do is usually applied. And of course, we can have a more fundamental part in that. I wouldn't distinguish between 100% fundamental or applied, either or, it is more like on a scale between them.

What does this kind of collaboration bring you, what is the value of it?

The collaboration with the industry brings some excitement and real life and the feeling of relevance. I am always very happy to see how people from society or industry are open to what you as a researcher can. bring. They open your doors for you. You can look into the kitchen. That excites me because it gives me a helicopter view over the industries. If the industry asks you as a university to give a some more detached view, you are able to do that. What society or industry would benefit from that is that usually industry is more oriented to the short-term and

midterm developments, and strategies. They have not so much time to really run innovations and implement them. You have a chance to give them the opportunity to make steps forward without disrupting their businesses. So, you can give them a push in innovating and improving, in professionalizing.

Does it help you to know upfront al about the expertise and knowledge from the industry, or do you rather know about that after your research and more as a help for implementation?

I think there are two sides. On the one hand, you have some people in practice that have something against new things, it disrupts. In those cases, I first have to try to convince them. Then my own opinions may be stronger than their opinions. It doesn't mean people from practice don't have a say or don't have a good argument. For example in our latest Lighthouse Project 'ExcaSafeZone', where we look into the work practice of people that do the excavation work, we interviewed them to identify what they perceive as safe. My belief is that we should take the stand that they are the ones that know how to do excavation safely. They do the work for a long time and why would they want to do their work unsafely. I truly believe that they are the ones providing me the knowledge, rather than me providing knowledge to them. But I have the analysis and a look at them all, and to see what the patterns are and feed that back to them. So, with that Lighthouse Project, we try to grasp what these excavator operators perceive as safe. We eventually want to develop an application using all their different kinds of knowledge. Using that to develop a system that integrates this knowledge into a decision support tool. They could then use it to further improve their excavation work. It is kind of a continuous process. We would like to interview them, develop the system, check whether it works for them, and so on.

Are there ever experts from practice that become real team members of your research teams?

I really look into how we map and use information about utilities for project management and for detection. I am not a geophysicist for example, but there is a man from practice that knows a lot about using ground radar and he tailors the use of that radar to detecting utilities. We have people that are more experienced in the technology itself, but we need these experts from practice to be involved if we want to do some project with radar technology. In a way, they give us more insights into that technology and we help them put the technology into new domains, civil engineering, and utility detection.

Is the implementation of your results, in the end, the main goal?

Yes. When I started doing my Ph.D. research some years ago, I felt almost a bit disappointed in the technology. Back then I was developing 4D visualization to support project management. And although I saw excitement, I also saw that they didn't use it after I left. I felt almost personally blamed that it didn't work in practice. So, at that point I felt we should be there, supporting the implementation to the very last end. Meanwhile, my opinion changed a little bit. As academic researchers, we should test the tools we develop, look at the feasibility of the tools, but not worry so much whether they work on the short term. More about whether they are implementable on a 5 to 10-year scale. What we invent may not be implementable directly because of some processes, or information flows, or whatever is not directly in place yet. But if we test and say it could work, it could support people from practice, then I am happy.

Given the fact that people from practice operate within a different world than the academics, that there are different perspectives, languages, different cultures, does that affect the collaboration?

That is a nice question. I think that in a general way, as academics we tend to think and analyze, and people in practice find an immediate solution. If there is a problem, there should be a solution. Their idea is to do things quicker, whereas a kind of rigor is also very important in academic work. So, finding people in practice

that are able to think in long lines and have a bit more patience is important. The problem shouldn't be solved tomorrow, but you should take the time to analyze things. Most of the times that maybe the people in more strategic positions. It may be more difficult with operational people on a project level. But in my own experience, I haven't really met a lot of people who were forcefully resisting everything we propose. The main challenge may be that they are sometimes asking a question that we need to answer quickly. And then we can't. We can only provide a thorough analysis. Or when they are not satisfied that we can't provide the answer either. We cannot tell them what they should do or what technology they should use. We can give them some insight into the advantages and disadvantages and alternatives.

Do you think you should be able to do that, giving them precise advice?

Sometimes we are forced to do that. In some projects where we had to analyze various technologies. that help to avoid excavation damage. We had to say: this could work, and this could work, but they both use different types of technologies and they both have disadvantages. They asked us what they should choose. We don't know what is best, it depends on what criteria they use. But we can help identify what is the most promising option. We can't look into the future either, but if we had to bet for it, we would do this.

Do you feel that in your schooling, the time at the university, you required enough skills and knowledge to be able to communicate effectively with people from completely different cultures?

Yes. My own Ph.D. research was actually sponsored by the industry. Ironically, I have never really had a very strong ambition to go into science, but I rolled into it because I was in practice and I saw things that were nice but weren't happening. I was very interested in how we could improve the practice.

Do you feel fundamental projects are still possible in construction?

What I get from discussions with peers and during conferences, is that as construction management engineers we have the problem that we don't get research funding from one particular stream. It is not that our research is funded only through large national programs like NWO, were they mostly focus on fundamental research. At the same time, sourcing only from industry is sometimes difficult because it is a fragmented industry. If you want to set up long-term projects, it is almost not possible to get the funding. I really would want to have them dedicated on the longer term, larger projects, rather than only collaborating on pieces of such a project.

How do you see the academic products you have to deliver, publications? Do you see that as an advantage next to the applied research and results, or as an obligation?

It depends on how you perceive the term 'obligation'. Yes, publishing is a very important part of our work. Scientists are often evaluated based on their publication record. However, one should not exaggerate this by focusing solely on publishing. The goal is not to get as many papers out into the world as possible, but to share results with the larger community. The publishing and writing should be to disseminate ideas and findings. And if you don't do that generic exchange with your peers then you never improve. You miss the review from colleagues that may have interesting opinions that can bring your own research further along.

Is there any topic related to Research to Reality that you feel we didn't discuss yet?

Perhaps as a scientist, you shouldn't be scared of going outside of your office. Going to reality is a must and it is really exciting to go to the practice and to speak to people. It may seem kind of safe to do your project inside, and I think it is also perfectly feasible to only do conceptual work, but you will find much more excite-ment in the interaction between the two, and not so much in isolating the two.

IN CONVERSATION WITH RIJK BLOK

assistant professor Section Structural Design, Department of the Built Environment, Eindhoven University of Technology and researcher for Lighthouse Project 'Bio Based Bridge'.

We have this Research to Reality and you could interpret it in a couple of different ways. Some of the most extreme are that you want to completely tailor you research format so that it can be implemented in reality easily and the other extreme could be that you have your research, fundamental or not, and afterward, you figure out how it can be placed in the reality. How would you see the relationship between research and reality?

Research and reality, well, very quickly you start thinking this is a way of marketing thinking, that research should be more usable and have very quick placement in society. And then solve problems and start to make money, or so. I think it is a little bit more complicated than that. In the end, I think that giving money for research or investing in research really deserves that we say what are we doing with the money for a society that provides this money. I think it is a good thing that people that do research give something back to society. So, research for the research, which is sometimes a little bit the case in very hard-core research-oriented departments, is not really what we are doing here in the department for the built environment.

Is that because of the culture of the department or the reality of the built environment world that you live in?

I think the department for the built environment is of course more about applied research. What are the problems in society and how can we solve them? And the problems that we are facing are about sustainability, about circular economy, circular building, people getting older, all those kinds of problems that are directly related to our well-being in this environment. If you talk about Research to Reality, then there is in the built environment always a strong connection to the problems we are facing. But sometimes 'to Reality ' also means: do some research, invent something, start up a company and we start making money. But that is actually quite difficult, there still is a big gap between what the built environment and the construction industry is doing and what the topics are that we research here at TU/e.

Can you elaborate on that?

For example, if you look at our own research project that we did for 4TU, making a bio-based bridge, that is already quite close to society in the sense that it involves with a design. Solving structural problems, but also problems of the materials, the composite materials. How to make them more bio-based or fully bio-based in order to really achieve a circular way of building. I think the research is a little bit ahead of all the troops because it is still is quite expensive as a material and the demand for that kind of material is still rather low. To have straight away a startup company that now starts producing bio-based bridges is a little bit too quick.

The reality of the builders, the built environment industry, is different from the culture of the academia, is there a big gap?

What we tried to do is to interest other parties in funding a PDEng. We do research, and the participating company has their people educated on the subject. The company we contacted actually did not show interest in funding research on bio-based materials and applications. I think that is in a way a bit short-sided and not really investing in the future. But that has also to do with the people that are now in charge of that kind of companies, they were educated quite some time ago, whereas you ask young people now, the students, they really have the drive to invest into sustainability and trying to achieve a more circular economy. I see a difference between the people that are deciding about money and the people that strive for actual change in our society for the better.

That is an example of the idea that innovation should be driven and funded just because of the fact that it has to be done, that it is relevant. And the idea that investments need to be earned back.

That is right, in five years time this company will recognize that it would have been a good idea to collaborate, but at the moment they don't see the urgency of investing in this.

Do you think that this collaboration or connection between research and reality is necessary?

What we see is that in research we need to collaborate, because problems are usually multi-scale or different items are involved. I would encourage collaboration as much as possible in projects. Maybe one Ph.D. on one sort of specific topic. But of course, we also have to do research which is playing around a little bit. I now have a student who looks at knitting for example, how can we use knitting in structures? That is an example where there is not a direct solution for a societal problem, but I am sure something will come out of it which is very interesting. I think you have to do both.

And the people at the university, are they skilled enough, equipped with enough tools, to collaborative with the industry in an effective way?

You mean the students?

Students, Ph.D.'s, researchers. Is it easy to collaborate?

I think it has become much better. A couple of years ago TU/e made the change to not just educating nerds, who in the end cannot communicate and cannot collaborate with anybody. They made a good change with the bachelor education to put more emphasis on being able to work in teams with a different background, people working together on a problem. And this is what happens also in reality. You still need those experts who are able to go very deep into a specific problem as well. But in the end, their results always need translation or needs communication in order to become implemented in good projects. I would encourage as much as possible collaboration with different experts and different fields.

So, how do you actually collaborate?

In the case of the bio-based bridge, we collaborated with a company called NPSP and they brought in their production knowledge and it became clear right from the beginning that for example, if you want to build a biocomposite element, usually you need an expensive mold system. It is really too expensive to make a special mold for one bridge, so we really looked into fabrication possibilities that did not have to use this expensive formwork. We used the internal core as the shape for the bridge and that was a good solution. What else? In biocomposites, there are a lot of material aspects that are related to the product, the type of resin, the viscosity of the resin during production is important, the exothermal reaction, how much heat is produced. All those are important aspects that influence the design as well.

Was the technology you got from you industry partner the reason to collaborate?

The reason to collaborate was also that this company is at the forefront of doing innovative structures. They are really interested in bringing this bio-based composite solution a step forward. So, they believed in it. It is about a vision.

Is this another 'reality' part? Being involved in technologies at the forefront of societal issues as sustainability, or circularity?

There are of course more and more people who want to move in the direction of being more sustainable, have less CO2 impact, be more circular. Sometimes that is a little bit on a political level. We want to go ahead without knowing too much about the technical details, or the problems behind them. We should do as much as possible on climate change problems. I don't know if we can, but I think we should do as much as possible and it is really necessary that we make a big change, not only with energy issues but also with materials. We have more and more people on this planet who use much more materials. If they all want to live in cities and urban societies, we need to change that a lot.

Do you think that is why your industry and client partners built the bridge?

For client partners, yes, there are always people that want to be ahead. We want to show what is possible. For industry, this drive is much less. They are still waiting and saying: this is how we make our money, this is our business model and we don't really want to change it. But I think we have to. This change really depends on politics. There is an ambition to be fully circular in 2050, that means very big changes.

Are there examples of research topics that originate from the industry?

Yes, sometimes. So, you mean where there are problems in society and they want to have a solution?

Yes.

Yes, but for this built environment faculty we have to be careful that we are not becoming a rather small research and development institute in a large field of big industries. I think it should be encouraged much more. Because before we know,

we are even behind if we don't take care of this. Also, I think in the industry there is a more natural way of going to universities of applied sciences rather than going to us. I don't know why that is, to be honest. I am a little bit amazed that sometimes in the university for applied science there is more money for research than in our university.

Is it about perception? The outside world thinking that universities are all about fundamental research and not about applied research.

Maybe. I was quite surprised to cooperate with the Avans University of applied science, they have a centre of bio-based expertise where there are a lot of people working, a lot of money involved, which is funded, which makes me as university a little bit jealous.

Do you have an idea about how you can get closer to a similar position?

If universities would have this seed-money, as we had in 4TU projects, it would really help. Because now we have this bridge. That generates more interest and we now also have a proven track record that we can use to achieve something new.

Would you say that research should be an integral part of education?

Yes, it should be as much as possible. For example, we made and designed this bridge with graduate students and also with students from applied universities.

So, education is good for the research. Why is it good for master students to be involved in a research project?

To get acquainted with new developments and new technologies. And also to develop a mindset, you have a problem, how can you solve it? I think that the department for the built environment is very good in a management approach to research. They know that at the end of all the design, there has to be a building. We are very good at circling around a preliminary design and then gradually making it better and better. And knowing that the first design decisions we take have very big consequences in the end. We also are able to do that in research projects. We know what the main problem is, and we try to focus on that. I think that for our graduate students to get involved in this kind of projects and research is a good thing.

Your question was quite good about the connection between research and education, ideally, it should be research, education, and industry together in bringing projects forward.

IN CONVERSATION WITH HANS-JAAP MOES

HR-executive, Executive Coach and Scale-up mentor, involved with Startupbootcamp, among others.

Can you very briefly say where you are coming from?

I am a philosopher and management expert and the past ten years I am focusing more on technology and on start-ups, leadership, entrepreneurship. I am supporting private equity investors to help start-ups to go to a next phase, to the scale-up phase, and if possible, go to a next level. Maybe to go to a public exit.

I have a special focus on leadership. What type of leadership is needed to make it possible to grow a business? Because in the end, 90 percent of companies are not growing. If you analyse why it is due to internal causes. So, it is not about the market, but they fail because their internal organization doesn't match the growth. Internal barriers make it impossible for growth to happen.

What kind of barriers should I think off?

In the first place the ability and willingness of the entrepreneurs to understand what needs to be done to make a big professional jump and substantial growth happen. The entrepreneurs need to reflect on what a fast growing company needs from them. They need to separate themselves from what the business needs from them.

And then go for it, although it might not always be their personal preference or favourite approach it needs to be done.

Another barrier is the number of transactions and administration, reporting, and filing which is exploding in a fast-growing company. You'll need someone senior to focus on operations, processes, rules, policies and more. Another big barrier is that the growing number of people. If you have a small group, you have informal communication, people know what's happening, they talk over lunch and everyone is connected, motivated and know what they need to do. But in the next phase, when there are more people especially goals and motivation are not obvious anymore. A first generation is connected, but a second or third generation of people in a company needs to be told, inspired and educated to show the same dedication to perform on a high level. And last but not least they need clear goals to perform and understand where to go.

If you talk about that first period, with the feeling of responsibility, you hear stories over working for 80 hours a week, is that true and is it necessary?

Yes, it is true and necessary. It is not only the volume, the number of hours, but it is also the weight of the responsibility. If you are a founder, you remember the time that every customer was hugely important, every customer is one. Your attitude towards customers and the idea of 'customer first', is part of your DNA. Next generations may have other priorities, doing something different in the afternoon or at the weekend and they approach the client maybe with a little bit less dedication, less passion than the first generation.

Are there other things on your list of barriers?

Communication is always a barrier. In a start-up, everyone knows everything about the company and people are connected. In a growing company, people know less and less about everything. They know a little about what's happening in the organisation and are also less connected. So, when new groups of people are coming in, they really need to be getting that start-up DNA as well and that takes some time. New people need to get inspired by the start-up story, the reason why it was established, to the problem it tries to solve.

Passion and mission are not self-evident, they need to be developed in the people. Entrepreneurs that argue they are special and everyone should understand this start-up is special doesn't show enough understanding and productive reflection and self-reflection of the fact the Scale-up phase requires the founders to be "dienstbaar" to their strategy and ignore personal preferences and emotions. This might cause a lot of insecurity and uncertainty in the entrepreneur.

Entrepreneurs need to put their energy into making the growth and next phase happen. Trusting others, delegate, explain, inspire and motivate others is not an easy transition from a start-up phase to the 50 people established company.

Maybe a last one in the top five of barriers for fast growth is the quality and development of the people in the company. In Silicon Valley, one of the key criteria for investment in Start-ups and Scale-ups is if the level of education of the people involved. Investors choose for start-ups with people from the best universities as this is a guarantee for fast learning, fast change and people that can cope with a very diverse and complex environment. You'll find many people that were fine when working in a very small organization but once it starts growing, they lack the flexibility and personal development for the next phase.

So, what you see in a lot of fast growing successful start-ups is that a few people, say 30% of the people in the start-up phase not survive the next phase. For them, you'll need to bring in new people that do understand next phase company experts. One of the new roles need in a fast-growing company, next to Sales and Product is Operations. You'll need a kind of COO, partly because of the earlier mentioned explosions of transactions, processes, reporting and numerous administrative procedures in the organization.

Are success and fast growth always fun and positive?

No, not at all. A start-up has an Informal and family type of culture. It has almost no structure. Larger organisations have rules, structure, processes, etc. And also with conflicts and confrontation with your old friends.

You talk about entrepreneurship, you talk about running a business, dealing with clients, but you don't talk about the product. What would you say is more crucial to create a good company, the product or the entrepreneurship? Because if I hear your story well, the product seems only a small percentage of the value of the business.

No, no. The product is number one but in an earlier phase. In the first phase, you start to work on products only. That is in the start-up phase and in the pre-start-up phase. If you are at the university or in your garage with your friends, it is all about the product and of course, you do a little bit of validation. You assume there is a market and sometimes you see the market, but it still needs to have more validation. The next phase is all about making it happen, about sales and/or having pilots to prove the value of the products and services. Product and sales are the first two priorities of any start-up.

What you have described until now is for start-ups with venture capital. Is this also valid for a more traditional - own money- business?

Yes, it's also valid for them, but there's less pressure for businesses with no outside investors than for start-ups with investors. As investors want to make a lot of money in a short period, a more traditional, organic growth and development is replaced by a forced, artificial type of growth. Both the people and the organisation need to make a kind of jump to a new level, which requires strong reflective and executive power of the leadership. The strong competition in the different area's of technology reinforces that force to grow at artificial and maybe even unhealthy speed.

Are start-ups and scale-ups nowadays offering services and responding to existing demands? Or do they need to create their own markets for their products and services?

Push is growing over Pull. If you look at applied new technology, like the internet of things, smart cities, big data, etc, It is not the market asking specific apps and products, but the start-up creating smart products and solutions, convincing the government, city government, it will help them to save millions.

Let's talk about academic research. It seems research is more connected to product development research, to the first phase, the pre-phase. How is that connected to "going to market?

I would say that the connection between academic research and the market is limited by nature. "Research is embedded in the academic world and it is not much fuelled by signals or impulses from outside. Should that change? No, I would say: let's focus on the product and subsidizes academic research. What could be done, in an early stage of research, is involving people that look from a market perspective towards that first phase. When more fundamental research develops towards more applied research, you could also have "market-people" coming in to explore and discuss business-potential. You could maybe try to influence the direction of the research in the future.

Do you see that influencing happing in research?

It depends on how the research is sponsored. If it is sponsored by Shell or another multinational, you will see from the beginning that there is that focus. It also depends on the discipline, for example, high energy research in space asks for academic research as well. You could think of very fundamental research, but they translate that stuff very early for example to smart city and gathering data. So, this research you wouldn't expect to be 'applied research', but if people look from

a distance to that research, they will find applications, some of them are in the kind of extensions of the research, you would expect. There are very surprising possibilities, people see markets because of a different perspective on the same research.

Do you see a higher rate of success of implementation or application within those collaborations?

I don't think I have enough data, but on my intuition says yes. It is a 'numbers game'. You could still say 399 out of 400 start-ups will not always fail but they will not make a critical mark level of 10-20 million in revenues. So, that 'numbers game' is probably also valid in academic research. It is difficult to measure success. But I would say that if you have an early perspective on possible market applications, it will help a lot.

What I found in my earlier conversations is that is in our branch it helps to collaborate with the industry and others to understand the implementations, possibilities, and conditions. I see at least a crucial difference between expertise and skills in the academia and in the industry. But the industry people come from academia, so there should be some kind of relation. But it looks as if there is a cultural difference in looking at things.

Interesting view. I started my carrier at Philips. They were producing goods. That involves another technology than in the software industry. Software is easily scalable. With Philips, and that is similar to the construction industry I think, sometimes the prototype took half a year, but then it took at least another year or sometimes longer to do what they call pre-production. Which means that you have a prototype, and yes, it is a great product, but before you are able to produce the product in mass production or in large numbers, you need to make machines that are able to do that.

In 1987 I started my own company, Socrates, and I had a guy in our office-building who was producing very light glasses for a microscope, so you could immediately read the number of particles in that little glass. But their production was micro-production, it took him 6 years to prepare that production.

I want to go back to something you mentioned earlier, in Silicon Valley sometimes it is very important from which universities the team members are coming. What kind of skills are they looking for?

Hard workers, mostly from scientific studies, preferably from Stanford, Harvard, Oxford, with a high intellectual level that have the skill to handle complexity and diversity and are able to reflect on themselves, the business and the roles to play. One of the things investors realize is that in the organisational dynamics, a lot of products are reinvented during the process, twisted or pivoted and the product for today is not the product of the future.

So that is what they look for: the smart students?

The learning capacity is key for an investor. I did see a start-up receiving 2,3 million US dollars without any product. Just because it is was a team of very smart people. They do have a direction of business thinking to go, they analyse and after that, they start thinking how to apply the general service, or product, in a market.

Is there a similar approach on searching for talent here in the Netherlands, in Europe, compared to the US and Silicon Valley?

No, not really. Here I see less focus on individual qualities. All Dutch universities are in the first 200 of a global list. They are all O.K., but we don't "Top-10" universities. Here your individual marks at school and your grades at the university are less important than in the US. The Americans, more than we do, want people that never give up, which is guaranteed if you have been to Berkeley, Harvard or Stanford because you cannot survive in those environments very hard working.

You have been involved last year in some of the activities we do, including the Research to Reality pitches to clients and investors. How do you validate the teams?

There were teams presenting themselves as a potential start-up and there were some other teams that presented themselves as academics. Some did not have a clue about what entrepreneurship means and how to develop a product for a market. That's my opinion about the Lighthouse Projects. To make the researcher less academic you could integrate more business-approach in the curriculum.

Are there any specific skills or things that would help these researchers' chances to get closer to a start-up or implementation of their ideas?

In general, start with a product, in a pre-start-up phase. Most of the Lighthouse projects were in that phase of development.

The lighthouse project pushed them into the arena and challenged them to think about markets. That's a great thing to accelerate entrepreneurial thinking. To me, they seem to enjoy this process. But instead of running this intense program now, you could integrate the "market-thinking" in the day to day activities in an early phase, thinking about what type of market would be interesting. What are the first priorities or barriers they would experience if they would go to market with their product? Maybe a market guy is looking over your shoulder and sees what to do.

From your experience, bringing start-ups to growth, what would you say is the role of academic research in the whole process?

I think it is crucial, without academics you have not a lot of fundamental research. In some industries, there is R&D, which can be fundamental. Without academic research, it would stop the whole engine of completely new things. If you look back at where the initial, or basic, innovations come from in technology. They come a lot from universities or from public industry, like NASA and those organizations, and less from the industry.

What do you think about the situation that research more and more needs to be sponsored by a combination of public and private or industry funds?

It is a very good idea. Stanford is a good example. The revenue of Stanford, their turnover is about 4 billion, so they have a huge machine and critical mass and great organization, and they can cope with that. What could be a problem in European countries, and I do see the Netherlands is too small, is that everything is too small. You are part of an organization that tries to connect 4 universities. Why? To a certain extent because they don't have enough critical mass as separate universities. One of the difficulties of giving public money to universities Is that a lot of people need to be involved in analysing and stating what has happened there. So, I would say that critical mass is an important element of making it easier to distribute the money. But is it important? It is hugely important, there is a lot of research that needs to be done. There is no industry interested yet. It is at an early stage.

And for that you need more money, but not from the Industry?

Yes. Like understanding how you secure data in the world. I think governments need to put in public money to make sure that in the far future, we are still safe.

Is there anything that you want to say that we didn't talk about?

I think one of the fun things about cooperation is the international aspect of it. In Dutch universities, even if it is a Dutch initiative, the professor is this German guy and if you look at the people in the room, they are from everywhere in the world. I think that one of the strong elements of entrepreneurship and success is to have all those people in the room. So, I enjoyed the program and I was surprised by some of the products, I thought they were great.

Physical things, it was all very nice to see the prototypes and all these kinds of things. And the way you did the reporting and made the magazine and have a

kind of nice format, that is something that is missing on the technology side. I mean on the software side, the kind of care you have and also the love you have for the product. At the same time, I would say because you are producing, it needs a huge amount of effort to get to the next phase. Much more than when you make an app or make software. That makes it as a business much riskier and much harder to grow to a profit. If you build a product and you want to sell, you will see that investors, in general, are less interested in construction innovation then in innovation in software and algorithms and apps.


CAST
FORMWORK
SYSTEM
EEL
THEMAZONE
SMART STEEL

RESEARCH
2014 – 2017

Lighthouse Projects
PDEng Projects
Research to Reality Projects

The 4TU.Bouw Lighthouse Projects program aims for imaginative research projects. Through yearly open calls among the researchers of the 4TU.Bouw faculties, a selection of proposals have each been granted a funding of € 50,000,-. The main criteria for selection are: at least two faculties from 4TU. Bouw are involved, the 'imaginative' nature of the research proposal, and the promise of a tangible result (e.g. prototype) within the project term of one year. The program has been set up as a 'seed money' approach; relatively small funding amounts, fast time-frame, set for 'proof of concept', or 'proof of failure'. A testing ground for extreme and 'out-of-the-box' ideas.

4TU.Bouw supports a selection of PDEng programs within their affiliated faculties. A PDEng program is a two-year professional, post-academic program, in which university graduates work in close collaboration with the industry on an urgent and industrially relevant topic.

The Research to Reality Projects were selected through an open call for pitching research proposals to an audience of potential clients and investors during the Research to Reality Conference in 2016.

The world's first MDM-printed concrete bridge for bicycles in Gemert, Noord Brabant, on opening day. The printed layers contain steel cable as lateral reinforcement (the bridge is prestressed in the longitudinal direction).

3D CONCRETE PRINTING FOR STRUCTURAL APPLICATIONS

Recent years have seen a rapid growth of additive manufacturing methods for concrete construction. Potential advantages include reduced material use and cost, reduced labor, mass customization and CO2 footprint reduction. None of these methods, however, has yet been able to produce additively manufactured concrete with material properties suitable for structural applications, i.e. ductility and (flexural) tensile strength. In order to make additive manufacturing viable as a production method for structural concrete, a quality leap had to be made.

In the project '3D Concrete Printing for Structural Applications', 3 concepts have been explored to achieve the required structural performance: applying steel fiber reinforcement to an existing printable concrete mortar, developing a strain-hardening cementitious composite based on PVA fibers, and embedding high strength steel cable as reinforcement in the concrete filament. Whereas the former produced only an increase in flexural tensile strength, but limited post-peak resistance, the latter two provided promising strain hardening behavior, thus opening the road to a wide range of structural applications of 3D printed concrete.

Fig. 1 Parallel section of 3D printed concrete element, containing 6 mm steel fiber. (source: Raedts, W., MSc graduation, TU/e, 2017).

The 3D Concrete Printing (3DCP) method, under development at the TU Eindhoven, is one of an increasing number of methods for the Additive Manufacturing of Concrete (AMoC) under development around the globe. Until recently, however, the lack of ductility and (flexural) tensile strength that could be obtain in the printed product severely limited the scope for which these methods could be applied in structural applications. This problem has been addressed in this project. Three conceptual solutions were developed: applying steel fiber reinforcement to an existing printable concrete mortar, developing a strain-hardening cementitious composite based on PVA fibers, and embedding high strength steel cable as reinforcement in the concrete filament.

Steel Fiber Reinforced 3D Concrete Printing

The addition of steel fibers to concrete to replace conventional reinforcement bars or reduce it has been applied in concrete construction for several decades. Applying this concept to 3D concrete printing required the development of a device to add the fibers to the printed filament near the print nozzle, as the steel fibers would clog up and damage the pump and transport system due to their stiffness and abrasive nature. In the project, a prototype of such a device has been developed and tested. In its current state, it proved possible only to print concrete with a short 6 mm straight fiber, although the target quantity of 150 kg/m3 was reached. As expected, this resulted in strong strain softening behavior, but a significant increase in flexural strength was nevertheless achieved (Figure 1). The fiber orientation was highly anisotropic, with the majority aligned in the direction of filament flow, as shown in a cut open sample (Figure 2).

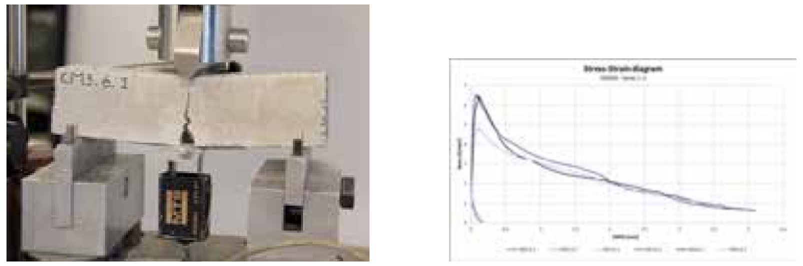


Fig. 2a, b CMOD test and resulting stress-CMOD curves for printed beams, without fiber (CM3.0.1-3) and with 6 mm fiber (CM3.6.1-3). (source: Raedts, W., MSc graduation, TU/e, 2017).

Fig. 3 Printing with one of the developed PVA-fiber reinforced Strain Hardening Cementitious Composites.

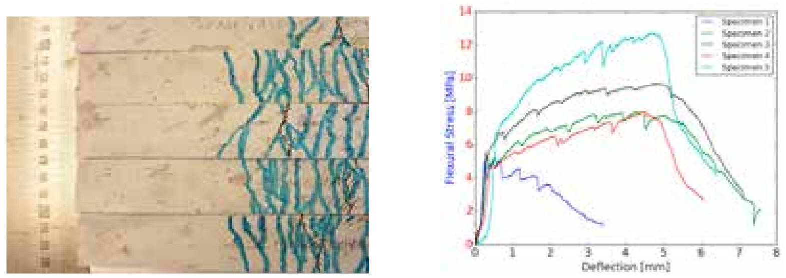


Fig. 4a, b Printed PVA SHCC specimens after test with cracking pattern indicated and stress-strain curves from 4-point bending test.

Fig. 5 3D printing concrete with a directly entrained reinforcement cable.

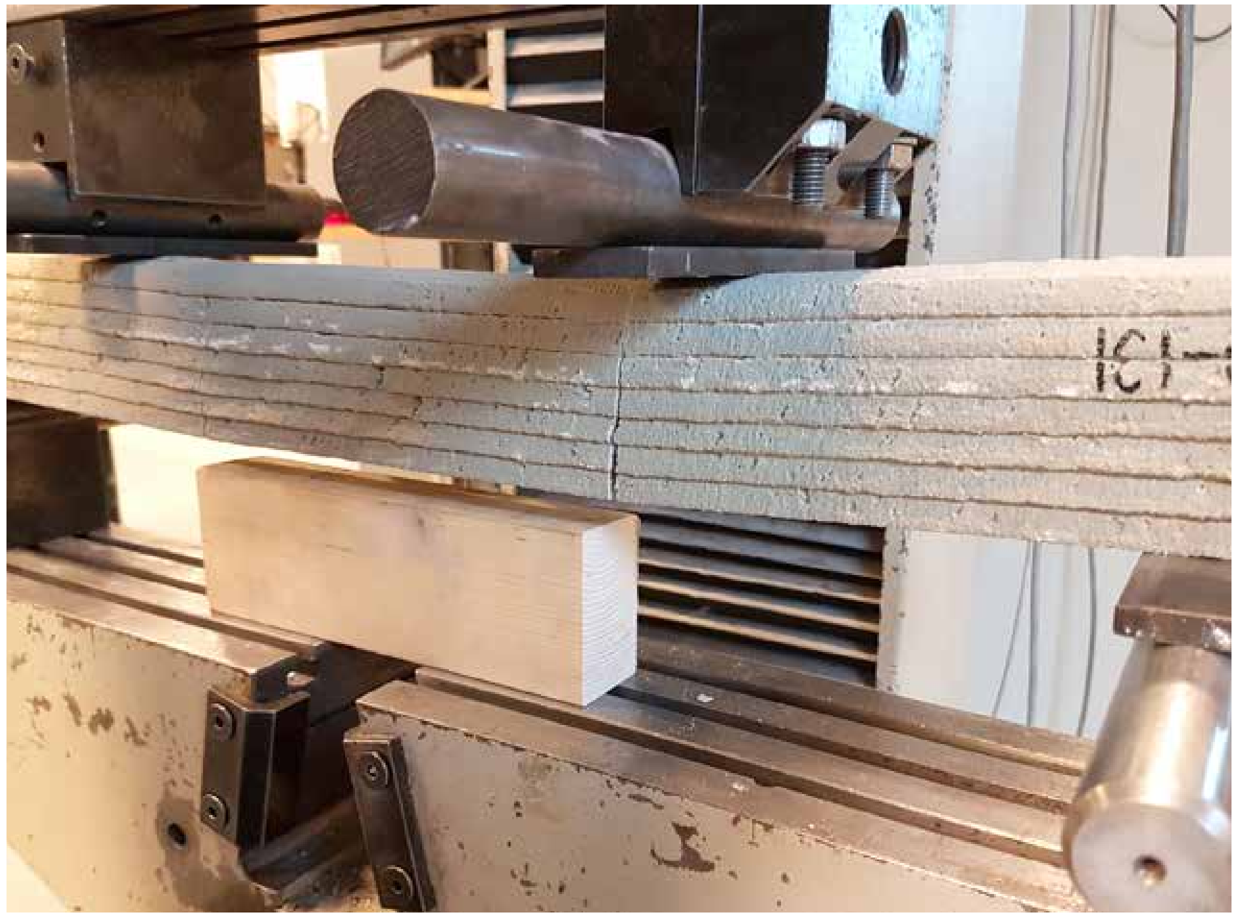


Fig. 6 Bending test on 3D printed concrete beam with cable reinforcement.

PVA Fiber Based Strain Hardening Cementitious Composite

Recently, strain hardening cementitious materials have been developed. These are based on the application of very finely distributed PVA fibers, which possess a relatively high strength (for polymers) and excellent adhesion to concrete. These materials are usually self levelling. For the purpose of this project, a material was developed based on an extensive rheology characterization in relation to the properties of the 3DCP facility. After an intense trajectory of fine-tuning the material properties, two printable mix designs (Figure 3) were obtained that both showed clear strain hardening behavior (Figure 4). Due to the flexibility of the PVA fiber, they could be added to the initial mix and be pumped to the printer head. Contrary to the steel fiber, no additional device is required although a careful mixing of the fibers in highly viscous mix proved crucial to avoid clogging in the linear displacement pump. The structural performance of the materials that have been developed is extremely promising and will be the subject of future research and development.

Steel Cable Reinforced 3D Printed Concrete

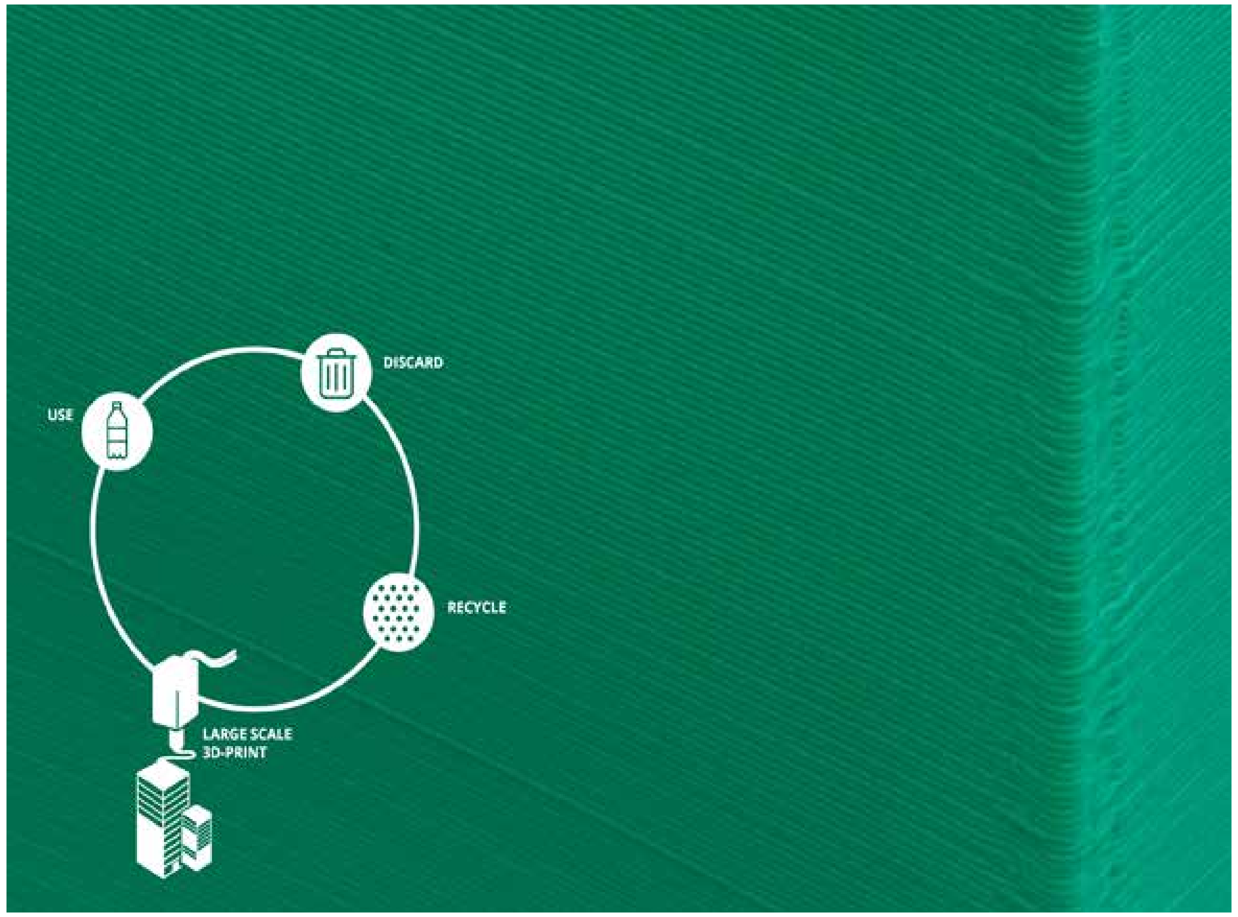
A completely different approach is to rethink the conventional reinforcement bars and apply highly flexible high strength steel cables instead. A device was developed to entrain the cables in the concrete filament during printing (Figure 5). Pull-out and bending tests were performed using 3 types of cables of different strengths (Figure 6). It was confirmed that common calculation approaches for conventional reinforced concrete could be applied to cable reinforced printed concrete as well. Ductility is readily achieved, but strain hardening highly depended on the concrete element design, as in many cases the stronger cables failed in cable slip rather than breakage, and were thus not able to develop their full strength. Research to improve bond behavior is ongoing. Entraining steel reinforcement cable improves the structural safety significantly and was therefore applied as lateral reinforcement in the layers of the world's first MDM-printed concrete bridge for bicycles in Gemert, Noord Brabant. Several hundred meters were applied.

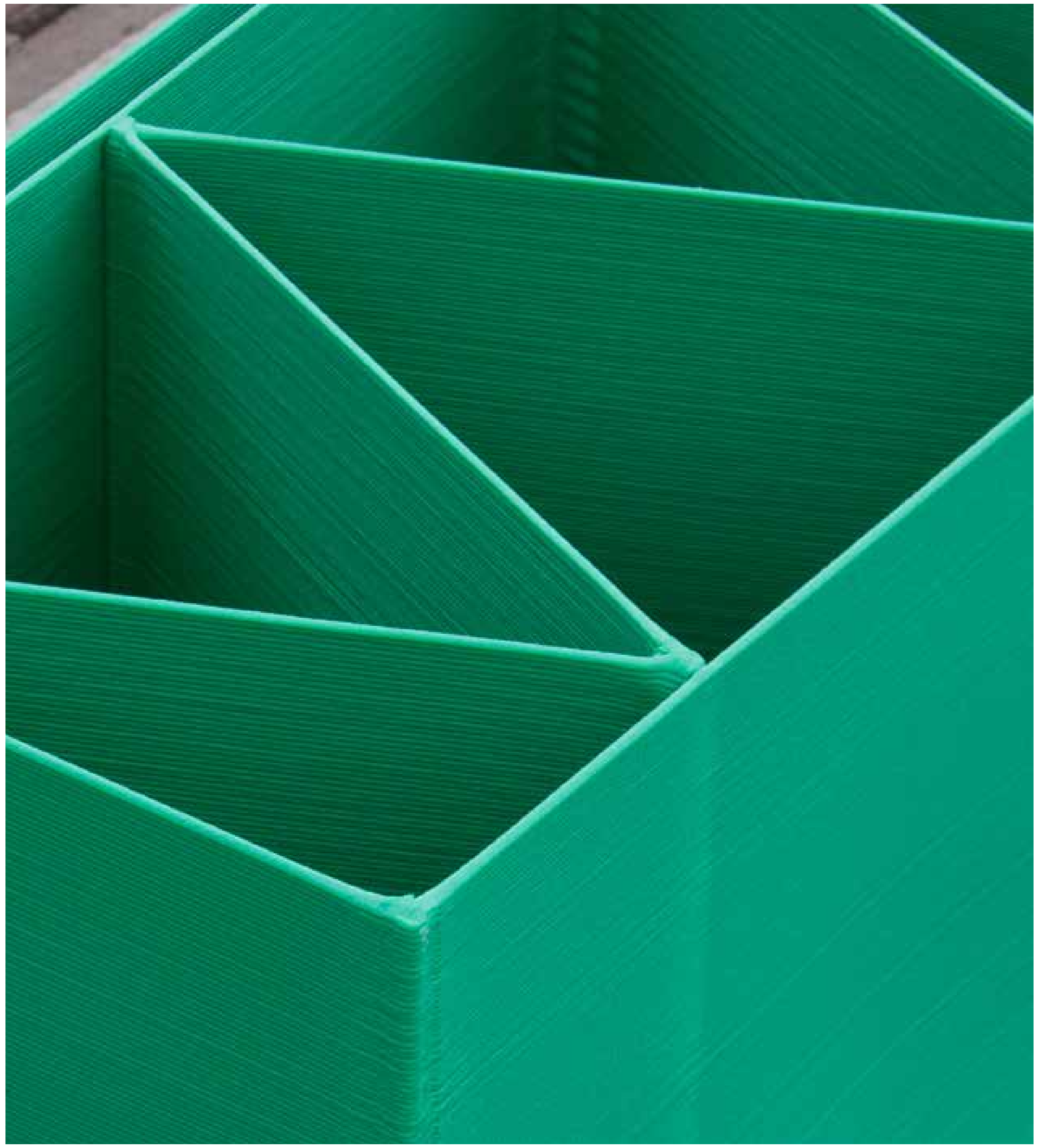
Concluding

The project '3D Concrete Printing for Structural Applications' has resulted in two quite different but highly promising concepts to achieve ductility and (flexural) tensile strength in printed concrete. This will greatly increase the possibilities to apply the new technology of 3D concrete printing to structural designs.

Eindhoven University of Technology
dr.ir. **Freek Bos, Zeeshan Ahmed MSc**

Delft University of Technology
Claudia Romero Rodriguez MSc,
Stefan Chaves Figueiredo MSc





3D-PRINTING IN THE CIRCULAR CITY

This project investigates the metropolitan challenge of the reduction of plastic waste. It introduces an innovative solution for the recycling of plastic waste, which takes advantage of large scale 3D-printing. A multidisciplinary consortium, consisting of TU Delft, Actual Build BV, AEB Amsterdam and the AMS-Institute combine their expertise and investigate this concept in the case study of Amsterdam North.

The local plastic waste streams are examined and assessed to define their utilization patterns and recycling potential. A selection of materials is tested in the laboratories of TU Delft for the definition of their mechanical and acoustic properties. The results of this test are used to produce a large-scale prototype of a bench that will be exposed in Amsterdam North. Besides recycling plastic waste, this approach is adding extra value to the built components due to the innovative advantages of 3D-printing, such as local production, customization, performance optimization, design involvement, etc.

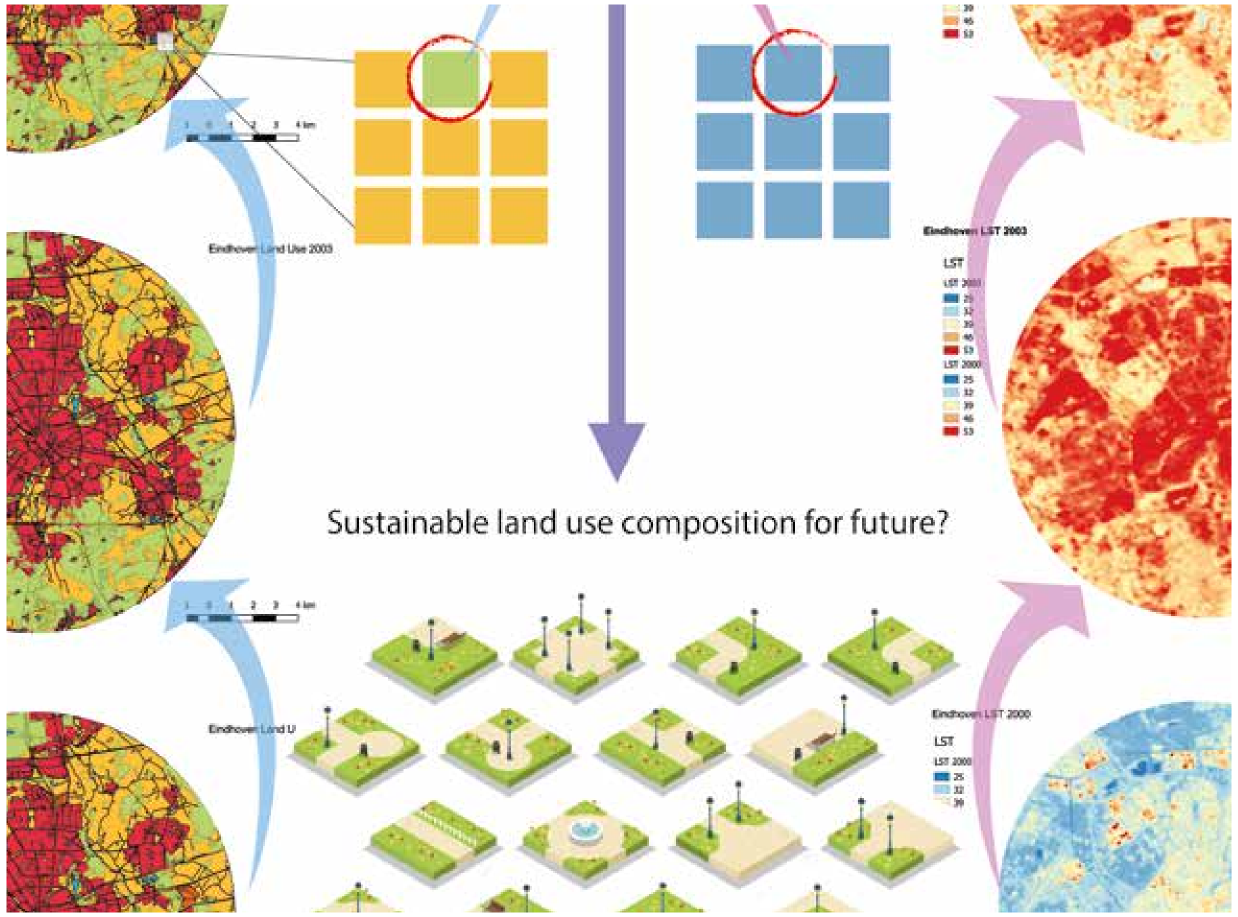
Delft University of Technology
Foteini Setaki, dr.ir. **Fred Veer**

The New Raw
Panos Sakkas

Actual Build BV
Martine de Wit, Ina Cheibas

AEB Amsterdam
Marieke van Nood

AMS-Institute
Virpi Heybroek



ADAPTING TO FUTURE CLIMATE THROUGH LAND USE

To adapt the urban area to the future climate and react to the global warming phenomenon, this project analyzed the dependency of land use and land surface temperature (LST) in Eindhoven area through 2000 to 2010. The goal is to achieve the Dutch government's target of COP22 and reduce the two degrees increase mentioned in KNMI climate report. To help the local government plan the city in a more sustainable way, the land use data from DANS and LST data from USGS in the selected year 2000, 2003, 2006, and 2010 have been used. The dependency model investigates the land use and LST change in the same geolocation through the time. In the end, the best suggestion for future land use composition will be achieved.

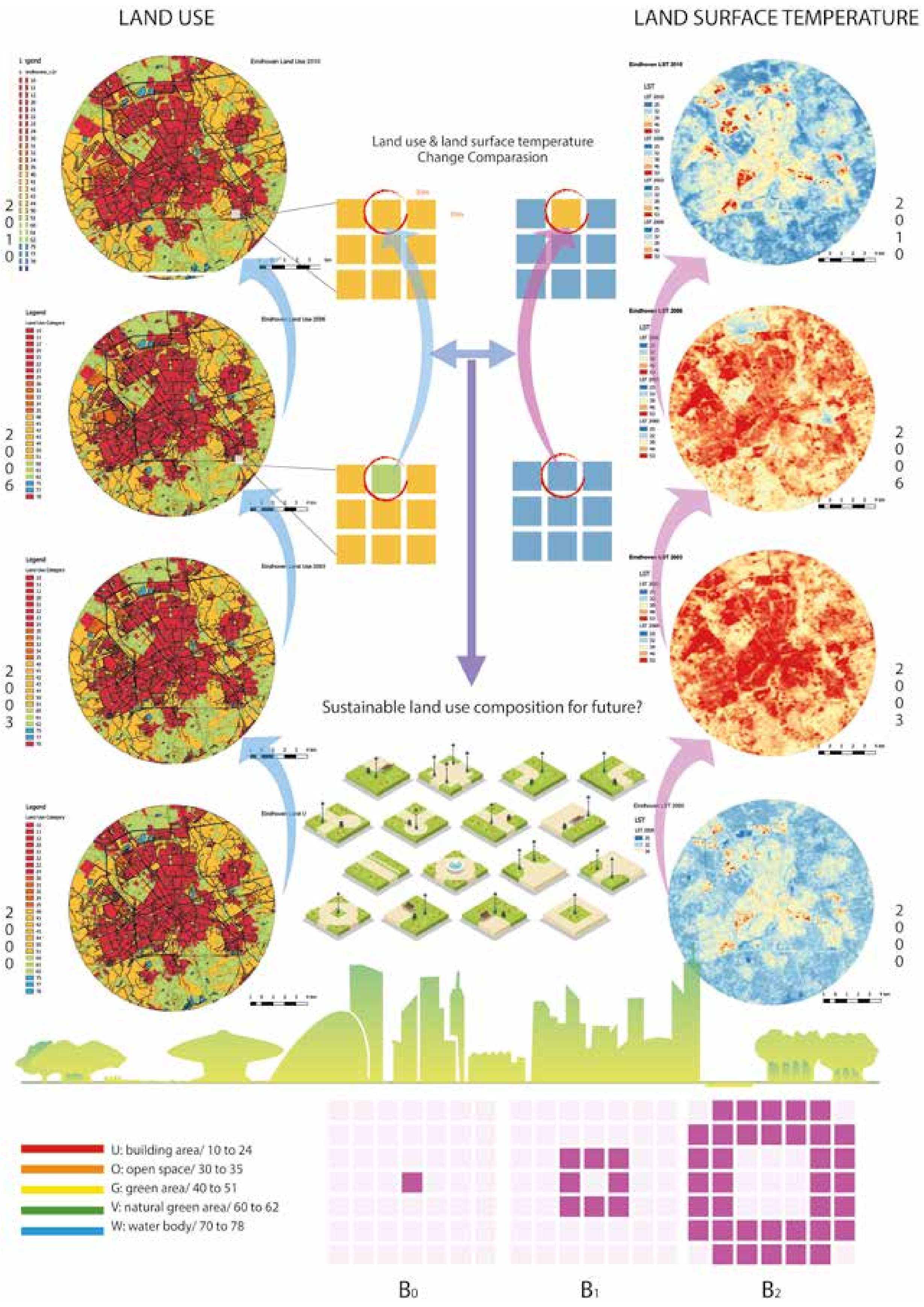
Urban Climate

Climate is changing our city and influencing our daily life significantly. The area of the built environment accounts for more than forty percent of the Eindhoven area, which is believed to have substantial contribution for the urban climate. Thus, we consider it as an urgent and necessary task for us to deal with the climate change on the urban level. The relation between urban climate and land use is however not analyzed so far. This project is targeting to achieve the Dutch government's promise on COP22 as well as retard global warming and UHI effect in the Eindhoven city, the Netherlands. To investigate the relation of urban climate and urban morphology, a lot of parameters need to be probed in this spatial model, for instance land use category, land surface temperature (LST), air temperature, normalized difference vegetation index (NDVI), built-up ratio, population density, gross floor area, etc.

For the first stage of the project, the land use and land surface temperature (LST) has been applied to analyze the change in difference years. We acquired land use data from DANS and land surface temperature data from Landsat 5, Landsat 7, and Landsat 8. The geometric resolution of the image is 30 X 30 m, which has been assigned as the cell size in this project. The selected area is a circle of radius 9 km from the central point, Eindhoven train station. The study area covers around 250 km^2 which contains 278,607 cells.

Data

The land use shapefile from DANS dataset originally contains twenty-six kinds of land use type. In this project, we categorized twenty-six into five kinds of land use type. The land use code "U" represents the built up area which contains the old code 10, 11, 12, 20, 21, 22, 23, and 24. The land use code "O" represents the open space area which contains the old code 30, 31, 32, 33, 34, and 35. The land use code "G" represents the artificial green area which contains the old code 40, 41, 42, 43, 44, 50, and 51. The land use code "V" represents the natural green area which contains the old code 60, 61, and 62. The land use code "W" represents the water area which contains the old code 70, 71, 72, 73, 74, 75, 76, 77, and 78. Among the study area, there are 40% of U (112229 cells), 36% of G (99731 cells), and following by 20% of V (56024 cells). The W and O cells only accounts for 1.6% (4490 cells) and 2,2% (6133 cells). The method of modifying data is clipping the study area from ArcGIS and the rasterized the shape file into the tiff file. The rule to determine how the cell has be assigned a value when mix land use falls within a cell is based on the maximum value of the attributes of the points within the cell. In other words, the land use category which occupies the largest area is dominant. Afterwards the rasterized map has been exported into csv file, and saved then modify inside excel based on its specific GIS location. The same step has been taken for the LST data.



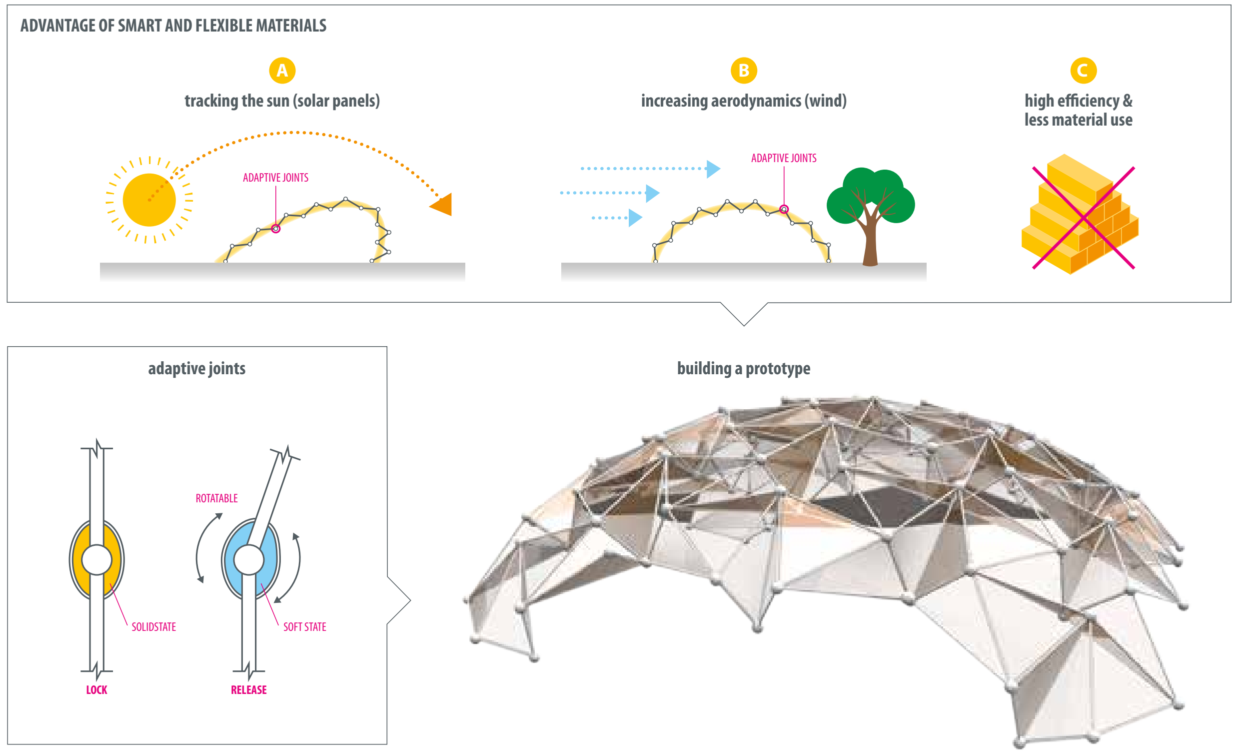
Results

The LST and land use data from 2000, 2003, 2006, and 2010 have been provided for the temporal comparison. The dependency of LST on land use is the objective of analysis through the changes over time at the same GIS location. The cell which changes its land use type has be compared with the cells that remain the same. Moreover, this project provide a comprehensive analysis of influence between the central cell and the neighboring land use type. Both distance and different type of land use act as parameters. The image illustrates the central cell (B_0), first ring of 8 neighboring cell (B_1), and second ring of the 36 neighboring cell (B_2). The LST is the dependent variable and land use is the independent variable. The analysis methodology we applied is the regression model from SPSS.

To conclude, the result shows that different kinds of land use types have different average LST within the year. Furthermore, the surrounding land use has positive impact on the central area´s LST. The correlation of land use and LST (r square) has increased while the amount of surrounding increasing. For the next step, we will use the findings here to conduct the exhaustive analysis between the years. Also, the seasonal comparison between summer and winter will be interesting. In the future, the urban land use can be planned in the sustainable way by using the result from this research and hopefully the urban environment can be redesigned such that it can adapt the climate change.

Eindhoven University of Technology
M.Arch. **Hung-Chu Chen**,
prof.dr.ir. **Bauke de Vries**, dr. **Han Qi**

University of South Australia
dr. **Conrad Heinz Philipp**



ADAPTIVE JOINTS WITH VARIABLE STIFFNESS

Most civil structures are over-engineered as a result of being designed to meet strength and rigidity requirements to withstand worst-case loading scenarios which in practice occur very rarely. The conventional approach to cope with these requirements not only creates significant material wastage but it also restrains structural and architectural design. Instead structures could employ adaptation through controlled shape changes in order to counteract the effect of loads (e.g. stress, deformation) and to achieve multi-functionality. Previous work showed that adaptive structures achieve higher level of structural efficiency [1, 2, 3, 4]. This project comprises numerical simulations and experimental testing to investigate an active and a passive adaptation strategy which employ variable stiffness materials.

Active adaptation

The structure is designed to 'morph' into optimal shapes as the load changes. This way stresses are homogenised to avoid peak demands that occur rarely. This way the structure can operate closer to design limits. Sensors (e.g. strain, vision), control intelligence, and actuation are strategically integrated into the structure. Simulation results have shown that savings up to 45% of material mass (and thus embodied energy) can be achieved with respect to passive structures [5]. Figure 1 (a) shows an illustrative example of a 20 m span arch truss whose shape is controlled against a lateral wind-type load. Figure 1 (b) shows a 1:25 scale physical prototype truss actuated by telescopic bars and whose joints are made of shape memory polymers.

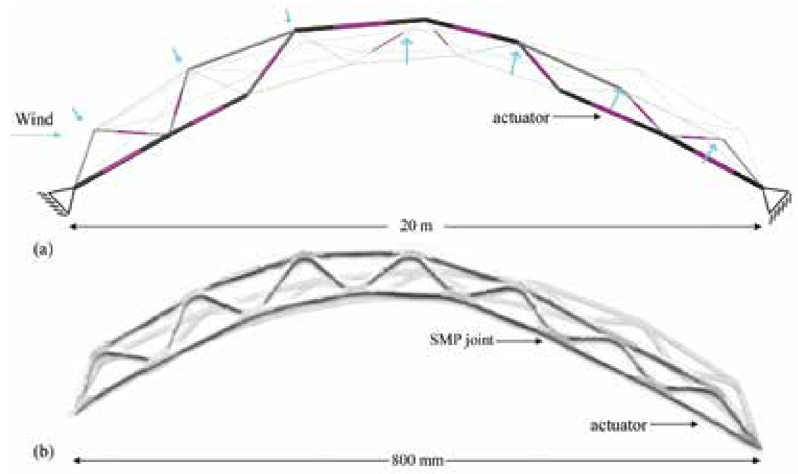


Fig. 1 (a) adaptive roof optimal shape against wind load; (b) 1: 25 scale prototype.

Passive adaptation

The structure is designed to change shape into pre-determined patterns in order to achieve multi-functionality. A chaise longue is taken as a case study. The geometry of the chair has been generated to accommodate an average human body either sitting or lying as shown in Figure 2. The required shape change from a "sitting" to a "lying" configuration is achieved by tuning the stiffness of the structure though strategic material deposition.

Experimental test

Stiffness variation is achieved by strategically arranged materials with transduction properties. Shape memory polymers (SMPs) can strain up to 400% featuring large variation of stiffness between a glassy and a rubbery state, which makes them good candidates for application in shape control of adaptive structures. Above the transition temperature (Tg) the elastic modulus is 3 orders of magnitude lower than that of the glassy state. The SMP chosen in this experimental study is called MM-5520 whose transition temperature Tg is 55°C.

Experimental Test

In both adaptation strategies, the structure is designed to work as a monolithic mechanism thus requiring a significant flexibility of the joints. To address this challenge, a variable stiffness joint is proposed [6]. Stiffness variation is achieved employing materials with transduction properties or by tuning material distribution strategically. In both adaptation strategies, the structure is designed to work as a monolithic mechanism thus requiring a significant flexibility of the joints. To address this challenge, a variable stiffness joint is proposed [6]. Stiffness variation is achieved employing materials with transduction properties or by tuning material distribution strategically.

Fig. 2 Chaisse longue shape change obtained by tuning the stiffness through material deposition.

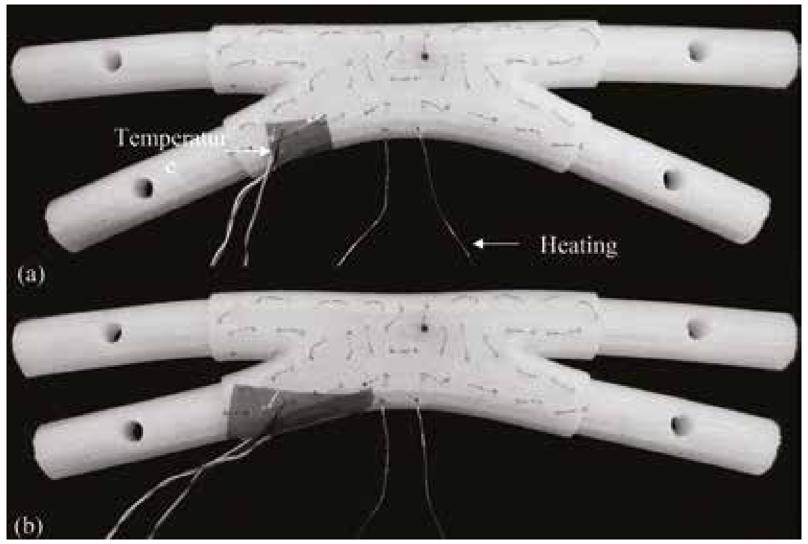


Fig. 3 (a) joint before heating, (b) joint deformed at an average surface temperature of 35°C.

Variable stiffness joints based on shape memory polymers

During shape control, the joint is 'actuated' to reduce its stiffness so that required deformation patterns can be achieved with low control effort. After shape control the joint recovers rigidity. Shape memory polymers (SMP) feature large variation of stiffness between a glassy and a rubbery state. This behaviour makes them potentially good candidates for application in shape control of adaptive structures.

A 1:6 scaled prototype with respect to the 20-m span arch truss shown in Figure 1 has been fabricated via fused deposition. Resistive heating is employed as activation method of the SMP joint. Figure 3 (a) and (b) shows the joint configuration before and after heating respectively. It is possible to deform the joint into the configuration shown in figure 3 (b) after 35 seconds when the internal temperature reached approximately the transition value (55°C) and the surface temperature has been recorded at 35°C [6].

An active frame made of four aluminium elements connected by a shape memory polymer joint has been tested. The frame is shown in shown in Figure 4 (a). The aim of this experimental study is to appreciate to what extent the fundamental frequency of the 4-element frame can be controlled through shape changes and joint stiffness variation. The elements are 20 mm diameter tubular sections with a wall thickness of 2 mm. A linear actuator (PC32 by Thomson Linear) is fitted onto each element. The SMP joint, shown in Figure 4 (b) has been fabricated via fused deposition. Resistive heating is employed as activation method of the SMP joint.

Measurements are taken after a shape change is completed before and after the joint stiffness is varied. As expected, the fundamental frequency decreases as the height of the structure increases moving from Shape 1 (the actuators do not change length) to Shape 4 (the actuators increase length by 300 mm). When the SMP joint is not actuated, the fundamental frequency reduces by 12.7% from 11.82 Hz (Shape 1) to 10.32 Hz (Shape 4). When the joint stiffness is reduced, the fundamental frequency decreases further to 9.90 Hz (Shape 4) which is shift of 16.23% with respect to Shape 1 [7].

Variable stiffness joints based on thermoplastic elastomers

The chair, shown in Figure 2 and Figure 5 (a) was fabricated via robotic additive manufacturing which is material fused deposition carried out by a robotic arm (Stäubli TX200, 6 axis). The chair is made of thermoplastic polymer (TPE) which

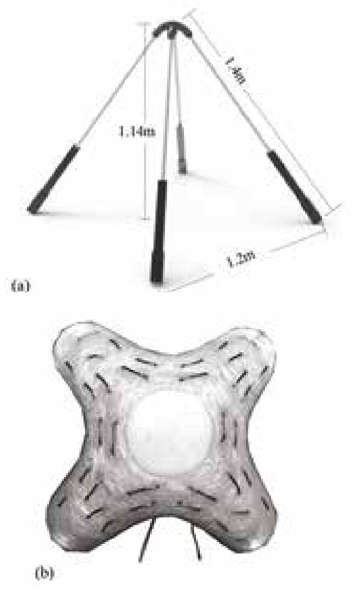


Fig. 4 (a) 4-element frame, (b) SMP joint.

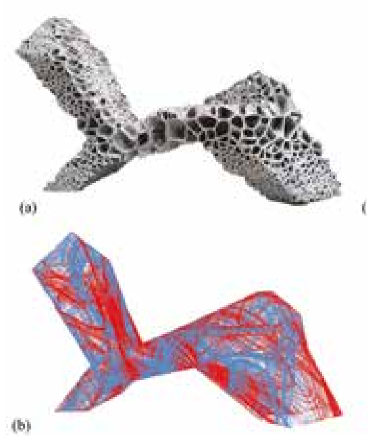


Fig. 5 (a) chaise lounge, (b) stress analysis.

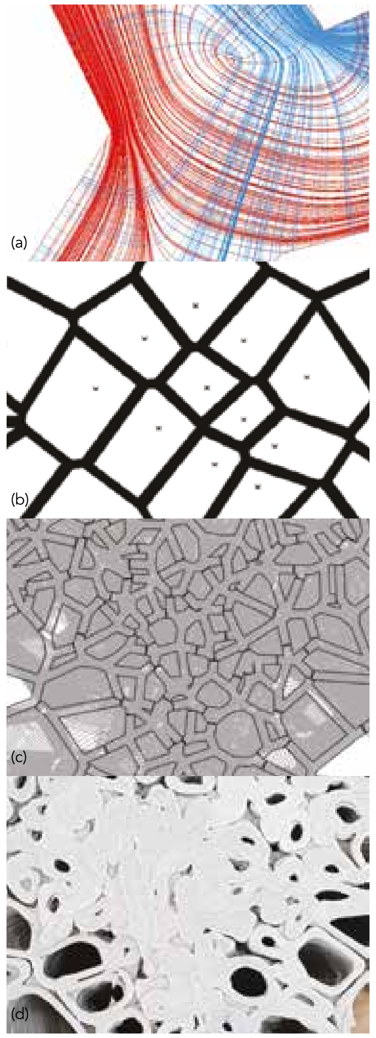


Fig. 6 (a) stress analysis detail, (b) subdivision pattern, (c) cell face section, (d) cell face section printed.

Eindhoven University of Technology
ir. **Qinyu Wang**,
prof.Dr.-Ing. **Patrick Teuffel**

Technical University Delft
Dr.-Ing. **Henriette Bier, Arwin Hidding**

Swiss Federal Institute of Technology
(EPFL, IMAC)
dr. **Gennaro Senatore**

can stretch significantly (300% under 2.4 MPa) and return to the original shape reversibly. The internal arrangement of material is a cellular pattern which is employed to create a self-supporting structure that can be fabricated by a robotic arm. Material deposition is driven by stress analysis as shown in Figure 5(b) and Figure 6(a). Material density is increased where high stress areas occur whereas porosity is increased where low stress areas occur. A 3D Voronoi pattern shown in Figure 6 (b) has been generated accordingly by varying cell size and wall thickness. Figure 6 (c) and (d) show a section of the cells as a 3D model and after being printed respectively. This approach was previously presented in [8].

Reduction of material waste has been obtained via optimisation of the angles of the cell faces. A custom agent-based algorithm has been developed to optimise each cell face orientation to lie between -45⍰ degrees and +45⍰ with respect to the printing bed. This way the robotic system can print without supporting material. The chair has been printed in 30 hours. The tool path has been optimised employing a traveling salesman algorithm that reduced fabrication time by 90% through minimization of the printer head traveling time between material deposition.

Conclusions

This work has shown that the use of variable stiffness materials, such as shape memory and thermoplastic polymers, has potential benefits for adaptive structures. Experimental testing has shown the feasibility of joint stiffness variation under quasi-static loading which could be used to reduce actuation work during shape control. Experimental testing of a 4-element active frame has shown that shape control combined with joint stiffness control is an effective strategy to tune the structure dynamic response to loading. Stiffness tuning through strategic material deposition has been employed effectively to achieve a required deformation pattern.

Further work involves studies that define the generality of these conclusions investigating scaling effects via testing larger scale prototypes. In addition, stiffness tuning will be investigated to improve comfort and durability by introducing cushioning and damping.

Acknowledgements

The authors gratefully acknowledge 4TU Federation who provided core funding for this project as well as 3D Robot Printing and 010Works who provided significant additional resources.

References

[1] P. Teuffel, "Entwerfen Adaptiver Strukturen," (Doctoral dissertation), University of Stuttgart - ILEK, Struttgart, 2004.

[2] G. Senatore, P. Duffour, S. Hanna, F. Labbe and P. Winslow, "Adaptive Structures for Whole Life Energy Savings," International Association for Shell and Spatial Structures (IASS), vol. 52, no. 4 December n. 170, pp. 233 - 240, 2011.

[3] G. Senatore, P. Duffour, P. Winslow and C. Wise, "Shape Control and Whole-Life Energy Assessment of an "Infinitely Stiff" Prototype Adaptive Structure," Smart Materials and Structures, vol. 27, no. 1, p. 015022, 2018.

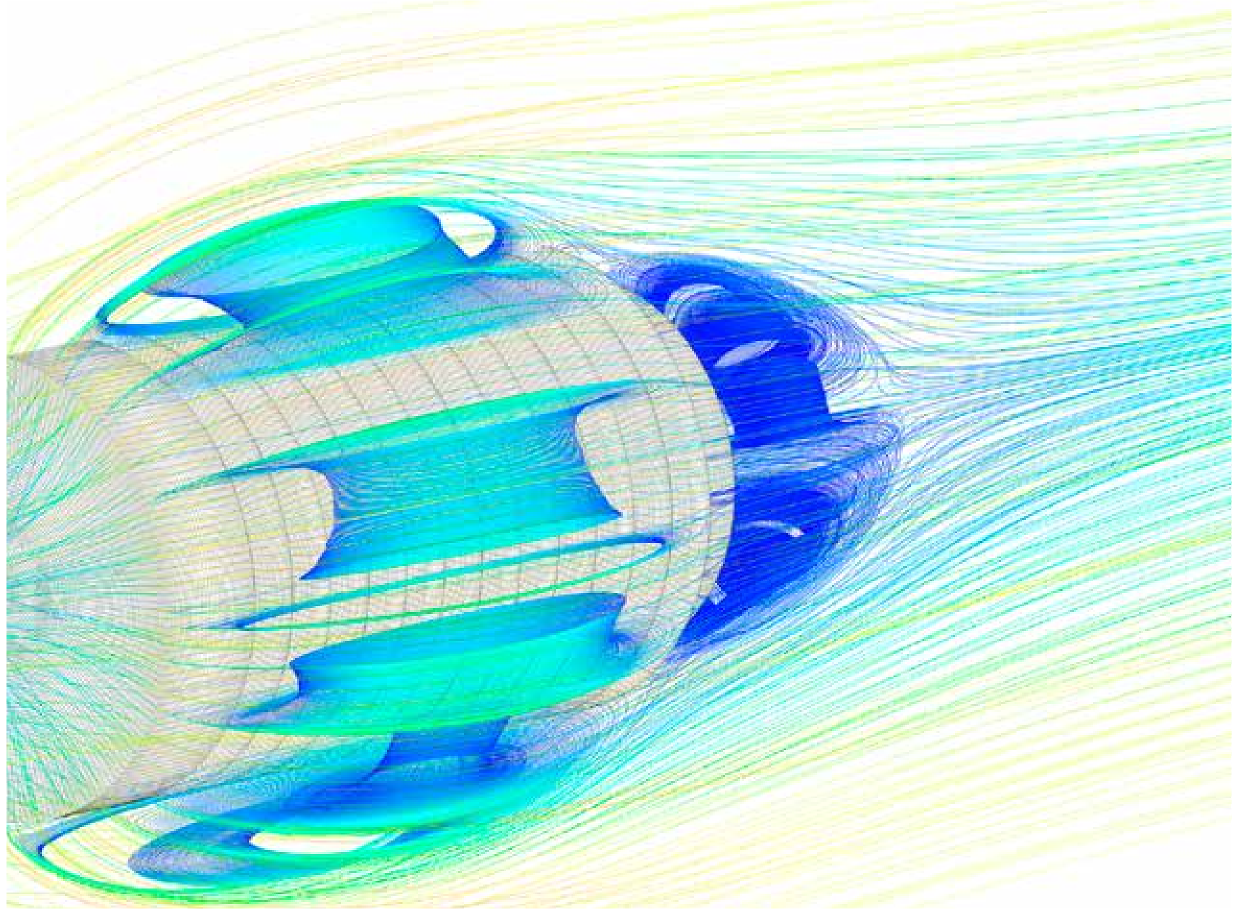
[4] G. Senatore, P. Duffour and P. Winslow, "Exploring the Application Domain of Adaptive Structures," Engineering Structures, vol. 167, pp. 608-628, 2018.

[5] A. Reksowardojo, G. Senatore and I. F. C. Smith, "A new method to design structures that adapt to loads via large shape changes," in International Association for Shell and Spatial Structures (IASS), Boston, 2018.

[6] G. Senatore, Q. Wang, H. Bier and P. Teuffel, "The Use of Variable Stiffness Joints in Adaptive Structures," in International Association for Shells and Spatial Structures, Hamburg, 2017.

[7] Q. Wang, G. Senatore, V. Kaymenaki, A. Habraken and P. Teuffel, "A vibration control strategy using variable stiffness joints," in International Association for Shell and Spatial Structures (IASS), Boston, 2018.

[8] H. Bier, S. Mostafavi, A. Anton and S. Bodea, "Scalable Porosity," in Imprimer le Monde, Centre Pompidou, Paris, 2017.



AERODYNAMC OPTIMIZATION OF PARTICULATE MATTER REMOVAL USING POSITIVE IONIZATION UNITS

The collection of all solid and liquid particles suspended in the atmosphere is known as particulate matter (PM). In urban environments, road traffic gives a major contribution (30% in European cities and 50% in OECD countries (WHO, 2005a)) to PM pollution due to high traffic intensities and corresponding tailpipe emissions and tire and brake wear (e.g. Rogge et al., 1993; Sundvor et al., 2012). Parking garages and tunnels are examples of locations where emissions are high and PM accumulates (e.g. Kim et al., 2007; Zhang et al., 2008), which subsequently disperse into the city. Furthermore, exposure to high ambient PM concentrations does not only occur outside, in streets where the traffic intensity is high, but also in buildings due to ventilation. Since people roughly spend 85-90% of their time indoors (Chen and Zhao, 2011) every single human being is exposed to certain amounts (highly dependent on local conditions such as traffic intensity, meteorological conditions and urban geometry) of PM on a daily basis.

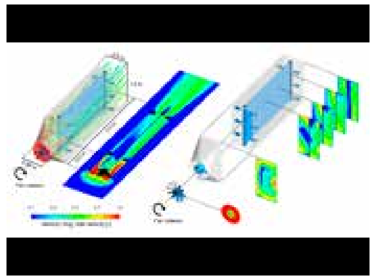


Figure 1 CFD analysis Aufero unit; contour plots and streamlines. Fan geometry is based on 3D-scan.Computational grid (unstructured) constructed out of approximately 17 million (tetrahedral) cells. 3D steady RANS in combination with the realizable k-ε turbulence model.

Effects of PM Exposure

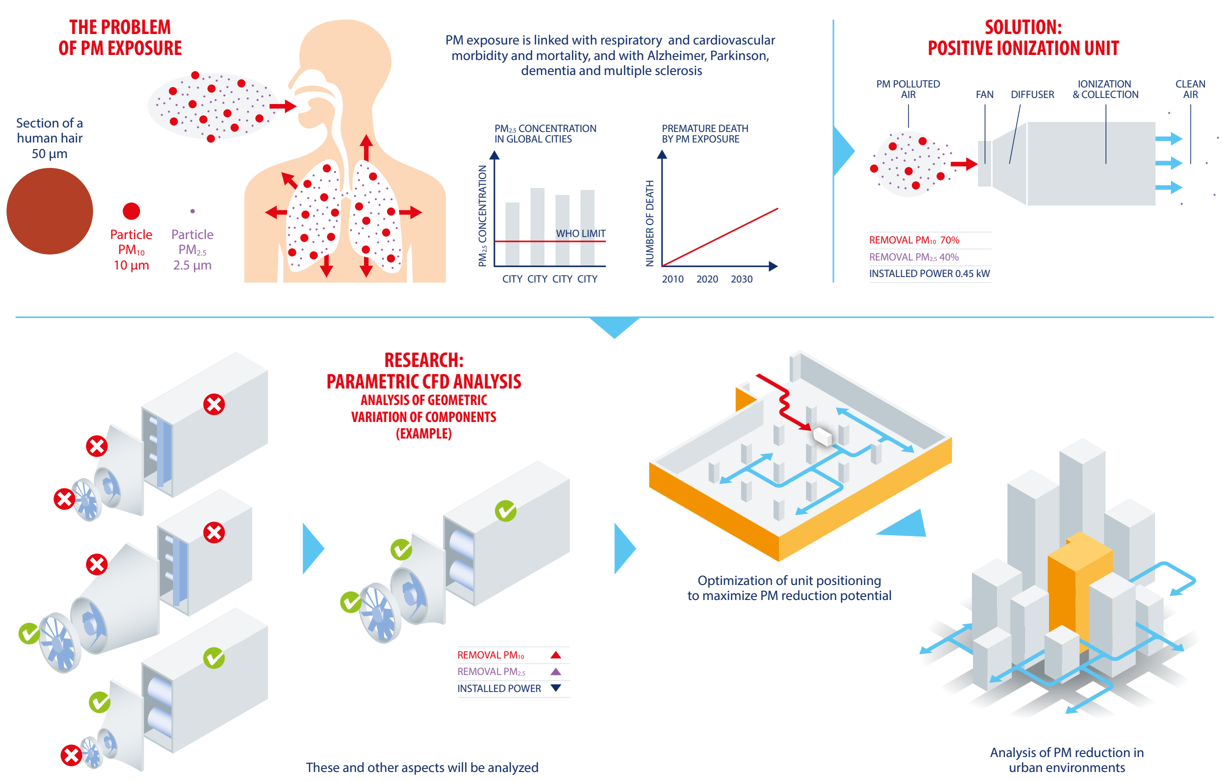
Worldwide, more than 80% of the people that live in urban areas are exposed to air quality levels that exceed the WHO limits (WHO, 2016). According to the OECD air pollution will become the world's top environmental cause of premature mortality by 2050 when no measures are taken. (OECD, 2012). PM is one of the most dangerous forms of air pollution; daily and long-term exposure to PM is strongly related to human morbidity and mortality (WHO, 2016). Several studies have linked PM exposure to respiratory, cardiovascular and cardiopulmonary diseases and lung cancer (e.g. Kunzli et al., 2000; Samet et al., 2000; Brunekreef and Holgate, 2002; Hoek et al., 2002; Pope and Dockery; 2006, Valavanidis et al., 2008; Raaschou-Nielsen et al., 2013; Beelen et al., 2014; WHO, 2013; WHO, 2016). Furthermore, links with multiple sclerosis, dementia, Parkinson's and Alzheimer's are found (e.g. WHO, 2013; Chen et al., 2017). So far, researchers have not been able to identify a threshold for which PM concentrations have an effect on human health, some individuals might be at risks when exposed to very low concentrations (WHO, 2005b). Most vulnerable are groups with pre-existing lung or heart diseases, elderly people and children (WHO, 2013). For the latter group, research has shown to affect lung development; i.e. lung functioning is impaired and lung growth rate is chronically reduced (WHO, 2013). Analysis shows that economic costs of air pollution, given that good health and a long life are highly valued in society, are significant (WHO, 2015).

PM Purification

Several techniques are availablwe to limit ambient PM concentrations such as wet scrubbers, electrostatic precipitators (ESPs), cyclonic separators and porous media filters (often known as high-efficiency particulate absorber (HEPA)). ENS Technology is a manufacturer of a PM removal units based on a positive ionization. The technology captures fine particles and ultrafine particles without the use of traditional filtering techniques. In the ionization unit, particles are bound together, forming coarse dust that is harmless since it is not airborne. One of the major advantages of the system is that most of the energy penalty, associated with the pressure drop across media filters, is eliminated. Various systems are available depending on the kind of application. The smallest unit is designed for the domestic, small business and catering market while the largest unit, with a volume flow rate capacity of 30,000 m3/h, is designed for companies with dust emission issues (e.g. companies in the food industry or agricultural sector). The product of interest in the present study, called the Aufero, provides a volume flow rate capacity of approximately 9,000 m3/h and is designed for indoor air treatment in industrial and commercial buildings but also for civil infrastructure (ENS, 2008).

Optimization of the Aufero Unit

Measurements performed by ENS show a filter efficiency of 70% and 40% for PM10 and PM2.5 respectively (ENS, 2008). The unit is relatively energy efficient and requires an installed power of 340 W. The aim of the first part of the company design project is to design an ionization unit with a higher removal efficiency for PM. The design process is supported by computational fluid dynamics (CFD) simulations. Simulations are performed using the 3D steady Reynolds-averaged Navier-Stokes (RANS) equations in combination with the realizable k-ε (Shih et al., 1995) or SST k-ω (Menter, 1994) turbulence model. First, the flow field of the current Aufero is analyzed to detect regions where the flow can be improved. It is desirable to maximize the interaction between the air and the electrodes to increase the efficiency of the unit. Important factor in this case is the flow pattern in the unit, i.e. absolute velocities and turbulence levels. Subsequently, parametric studies are conducted regarding different fan configurations, diffusers (shape, length and ratios) and other geometric variations. The analysis is conducted both



on unit scale (Figure 1) and component scale (Figure 2). The study focusses on the minimization of pressure losses (thus energy consumption for the fan) and maximization of the PM removal efficiency. Furthermore, attention is given to the fact that the design needs to be practical (regarding the manufacturing and maintenance process). Finally, the designed ionization unit has to be built and tested.

Application of the Aufero Unit

In the second part of the company design project an application (in this case a parking garage) of the ionization unit is considered. The goal is to optimize the location of ionization units inside the existing building infrastructure (including ventilation design). This process is again supported by CFD simulations (3D steady RANS in combination with the k-ε turbulence model). Preliminary results show that significant PM10 and PM2.5 reductions can be obtained inside buildings. For the case study as presented in Figure 3, a PM10 concentration reduction of 53% is obtained inside the parking garage for the measured ventilation scenario. Furthermore, analysis shows that the amount of PM10 that is emitted to the surrounding of the garage is reduced by 43%. It should be noted that several assumptions (e.g. spatial and temporal distribution of traffic, exclusion wind effects in the urban surrounding, exclusion of obstacles in the garage, and exclusion of the highly transient nature of the flow in the garage) were made to be able to perform these simulations. Further work focusses on more accurate and sophisticated modeling techniques

Although the study has some limitations, it indicates that large-scale application of positive ionization units can potentially reduce the air quality issues related to PM in cities. Previous research efforts (Blocken et al., 2016) also showed that large-scale application of ionization units in the parking garages of Eindhoven can lead to significant reductions of PM in the urban environment. Further work will focus on the validation of this concept.

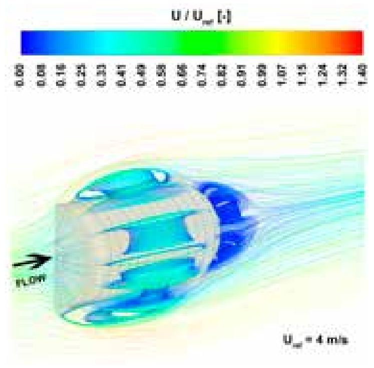


Figure 2 Component based CFD analysis; streamlines around isolator. Computational grid (structured) constructed out of approximately 4.9 million (hexahedral) cells (average $y^* \approx 1$). 3D steady RANS in combination with the SST k-ω turbulence model.

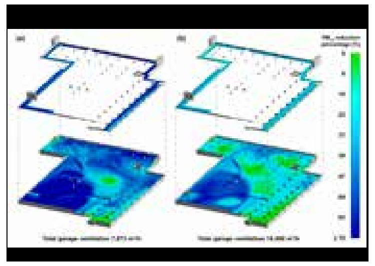


Figure 3 Contours of PM10 reduction percentage in parking garage; sensitivity analysis on garage ventilation rate. (a) Measured scenario: ventilation 7,973 m3/h. (b) Designed scenario: ventilation 18,000 m3/h. Computational grid (cut-cell) constructed out of approximately 9.1 million (cubical) cells. 3D steady RANS in combination with the realizable k-ε turbulence model.

Eindhoven University of Technology
ir. **Rob Vervoort**, dr.ir. **Twan van Hooff**, prof.dr.ir. **Bert Blocken**

The project covers several aspects, from design of the module and components up to the application of the modules in a building and its environment. Therefore the results of this project can contribute towards the development of smart and healthier cities by providing a possible solution for air quality issues in buildings and cities.

References

Beelen, R., Raaschou-Nielsen, O., Stafoggia, M., et al. (2014). Effects of long-term exposure to air pollution on natural-cause mortality: an analysis of 22 European cohorts within the multicentre ESCAPE project. Lancet, 383, pp. 785–795.

Blocken B., Vervoort R., van Hooff T. (2016). Reduction of outdoor particulate matter concentrations by local removal in semi-enclosed parking garages: a preliminary case study for Eindhoven city center. J. Wind Eng. Ind. Aerodyn., 159, pp. 80-98.

Brunekreef and Holgate (2002). Air pollution and health. Lancet, 360 (9341), pp. 1233-1242.

Chen, C., Zhao, B. (2011). Review of relationship between indoor and outdoor particles: i/o ratio, infiltration factor and penetration factor. Atmos. Environ., 45, pp. 275–288.

Chen, H., Kwong, J.C., Copes, R., et al. (2017). Living near major roads and the incidence of dementia, Parkinson's disease, and multiple sclerosis: a population-based cohort study. Lancet, 389, pp. 718-726.

ENS. 2008. Environmental Nano Solutions. www.enstechnology.nl/en.

Hoek, G., Brunekreef, B., Goldbohm, S., et al. (2002). Association between mortality of traffic-related air pollution in the Netherlands: a cohort study. Lancet, 360, pp. 1203–1209.

Kim S.R., Dominici F., Buckley T.J. (2007). Concentrations of vehicle-related air pollutants in an urban parking garage. Environ. Res. 105, pp. 291–299.

Kunzli, N., Kaiser, R., Medina, S., et al. (2000). Public-health impact of outdoor and traffic-related air pollution: a European assessment. Lancet, 356, pp. 795–801.

Menter, F.R. (1994). Two-equation eddy-viscosity turbulence models for engineering applications. AIAA journal, 32, pp. 1598-1605.

Organization for Economic Cooperation and Development (OECD) (2012). OECD Environmental Outlook to 2050: the Consequences of Inaction. 350 p. 9789264122246 (PDF).

Pope, C.A., Dockery, D.W. (2006). Health effects of fine particulate air pollution: lines that connect. J. Air Waste Manag. Assoc., 56, pp. 709–742.

Raaschou-Nielsen, O., Andersen, Z.J., Beelen, R., et al. (2013). Air pollution and lung cancer incidence in 17 European cohorts: prospective analyses from the European Study of cohorts for Air Pollution Effects (ESCAPE). Lancet Oncol., 14, pp. 813–822.

Rogge W.F., Hildemann L.M., Mazurek M.A., et al. (1993). Sources of fine organic aerosol. 3. Road dust, tire debris, and organometallic brake lining dust - roads as sources and sinks. Environm. Sci. & Techn. 27: pp. 1892–1904.

Shih, T.H., Liou, W.M., Shabbir, A., et al. (1995). A new k-ε turbulence model for high Reynolds number turbulent flows – model development and validation, Comput. Fluids, 24, pp. 227-238.

Sundvor, I., Balaguer, N., Mar Viana, X., et al. (2012). Road traffic's contribution to air quality in European cities. ETC/ACM Tech. Pap. 14.

Samet, J.M., Dominici, F., Curriero, F.C., et al. (2000). Fine particulate air pollution and mortality in 20 US cities, 1987–1994. N. Engl. J. Med., 343, pp. 1742–1749.

Valavanidis, A., Fiotakis, K., Vlacogianni, T. (2008). Airborne particulate matter and human health: toxicological assessment and importance of the size and composition of particles for oxidative damage and carcinogenic mechanisms. J. Environ. Sci. Health Part C – Environ. Carcinog. Ecotoxicol. Rev., 26, pp. 339–362.

World Health Organization (WHO) (2005a). Health effects of transport-related air pollution. http://www.euro.who.int/__data/assets/pdf_file/0006/74715/E86650.pdf

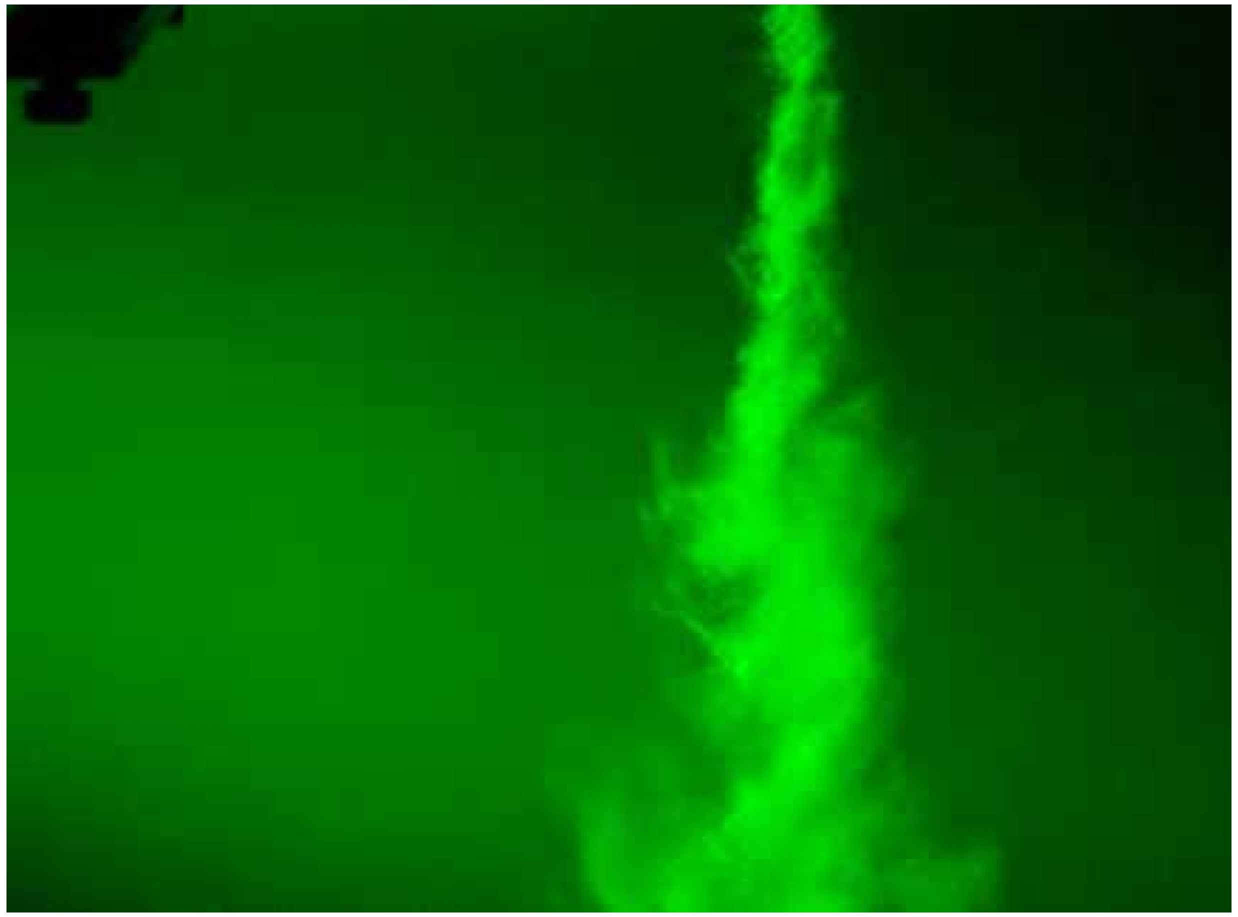
World Health Organization (WHO) (2005b). Air quality guidelines, global update 2005. Particulate matter, ozone, nitrogen dioxide and sulfur dioxide. ISBN 92 890 2192 6.

World Health Organization (WHO) (2013). Health effects of particulate matter – policy implications for countries in eastern Europe, Caucasus and central Asia. ISBN 978 92 890 0001 7.

World Health Organization (WHO) (2015). Economic costs of health impact of air pollution in Europe: clean air, health and wealth. http://www.euro.who.int/en/media-centre/events/events/2015/04/ehp-mid-term-review/publications.

World Health Organization (WHO) (2016). WHO Global Urban Ambient Air Pollution Database. http://www.who.int/phe/health_topics/outdoorair/databases/cities/en/

Zhang G.S., Li T.T., Luo M., et al. (2008). Air pollution in the microenvironment of parked new cars. Build. Environ. 43, pp. 315–319.



Photography Bart van Overbeeke

AIR CURTAIN OPTIMIZATION

The term "impinging jet" refers to a high-velocity fluid stream that is ejected from a nozzle, a narrow opening or an orifice, and which impinges on a surface. As applied to the built environment, impinging jets are used in air curtains to separate two environments subjected to different environmental conditions with the purpose of improving thermal comfort, air quality, energy efficiency and fire protection in buildings. The design and application of state-of-the-art air curtains requires detailed knowledge of the relationship between the separation efficiency of air curtains—their main performance criterion—and a wide range of jet and environmental parameters involving air curtain design. In order to address the current knowledge gaps in the field, this project encompasses an investigation into the impact of different jet and environmental parameters on the performance of air curtains while giving special attention to the study of innovative jet excitation techniques by means of optimizing the separation efficiency of air curtains. This project is being carried out in close collaboration with the air curtain manufacturer 'Biddle B.V.'.

The unique flow and transport characteristics of impinging jets have been of great interest across a variety of industries in processes such as cooling, heating and drying due to the fact that very high rates of heat and mass transfer can be accomplished with its implementation. Their application in industry includes the cooling of electronics and electrical equipment, cooling during the processing of steel or glass, gas turbine cooling, drying of paper or textiles, heating during food processing, freezing of cryogenic tissue and many more (Cho et al., 2011). In the built environment, impinging jets are used in air curtains to separate a controlled environment, in terms of temperature, pressure or concentration, from an unconditioned environment, while allowing an easy access of people, vehicles and material across the two environments. This separation aims to improve thermal comfort, air quality, energy efficiency and fire protection in buildings (Goubran et al., 2017; Wang & Zhong, 2014).

Air infiltration is responsible for a major share of the energy losses in commercial buildings, which can account for up to 25% of the total heat losses (Emmerich & Persily, 1998). For this reason, air curtains are typically used at entrance doors to minimize infiltration losses, in addition to reduce indoor air pollution and local thermal discomfort (i.e., draft and air temperature differences) (Frank & Linden, 2014). Furthermore, air curtains are frequently used in other specialized building system applications for the reduction of cigarette smoke propagation outside of smoking areas or in the event of fire (Krajewski, 2013; Luo et al., 2013); for lowering air contamination hazard in laboratories and hospital rooms (Zhai & Osborne, 2013; Shih et al., 2011); for retaining the refrigeration properties of cold rooms and display cabinets (Giraldez et al.,2016; Foster et al., 2006; Gil-Lopez et al., 2014); and for many other applications.

The performance of air curtains is commonly assessed based on the heat and/or mass exchange between the environments separated by the air curtain through the criterion known as "separation efficiency". Understanding how the separation efficiency depends on the involved transport processes and their influencing parameters, is essential for the optimization of current air curtains and the development of new air curtains.

The existing literature suggests that the alteration of jet and vortex characteristics by means of passive and active changes in jet parameters, including jet excitation, can have an important influence on the entrainment and transport processes of impinging jets. Furthermore, external forces can be present which alter the flow pattern of the jet and therefore influence the transport of heat and mass across the jet.

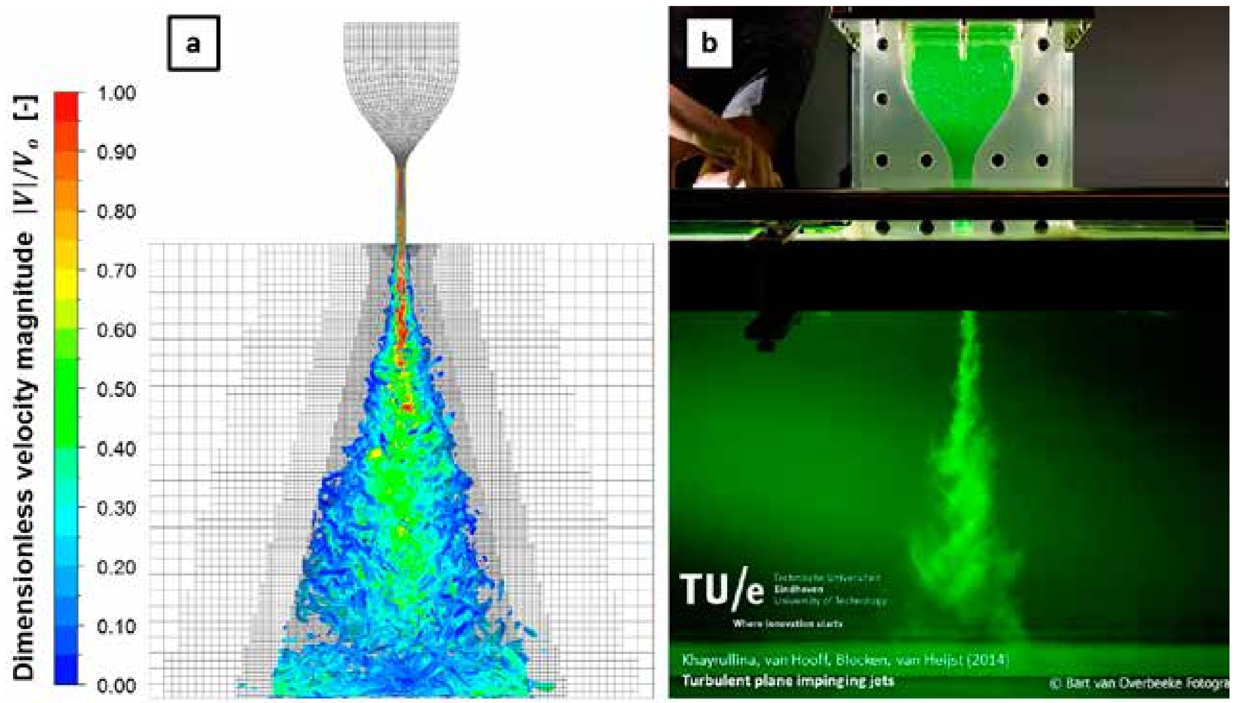
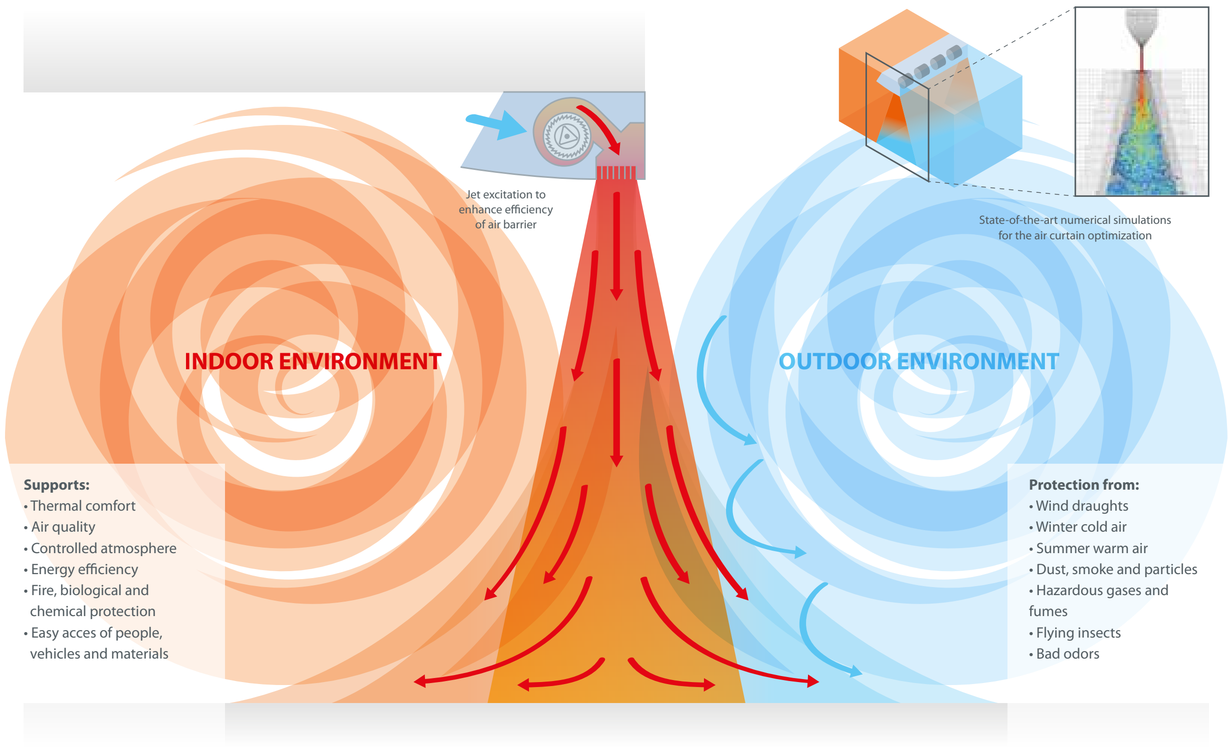


Figure 1 a) Velocity magnitude contours of an impinging jet obtained from CFD simulation (large eddy simulation). b) Visualization of impinging jet flow in a water tank experiment (Khayrullina et al., 2017).



In the case of air curtains, these external forces are typically a consequence of environmental parameters such as cross-jet temperature differences (natural draft) and pressure differences (wind pressure and building/room pressurization). However, the relationship between jet excitation, environmental parameters and jet vortex structure with the air curtain separation efficiency is not yet fully understood.

In order to address the current lack of knowledge on impinging jets, focused on their application in air curtains, and to support the design of new air curtain technologies, the project comprises the following goals:

1. Understanding the increase or reduction of heat and mass exchange through an opening with an air curtain when subjected to a variety of jet and environmental parameters.
2. Investigation of the influence of jet and vortical structures on the separation efficiency of an air curtain
3. Optimization of the separation efficiency of air curtains by exploring the influence of jet excitations on the jet and vortex behavior.

For the purposes of this project, numerical simulations using Computational Fluid Dynamics (CFD) are conducted to analyze the fundamental flow behavior, systematically evaluate the performance of air curtains under different operational settings and environmental conditions (i.e., cross-jet temperature, pressure and concentration variations), and parametrically optimize the air curtain efficiency through the incorporation of jet excitation techniques. These simulations have been accompanied with high-quality water tank experiments (Khayrullina et al., 2017) and field measurements (Biddle B.V., 2016) for validation.

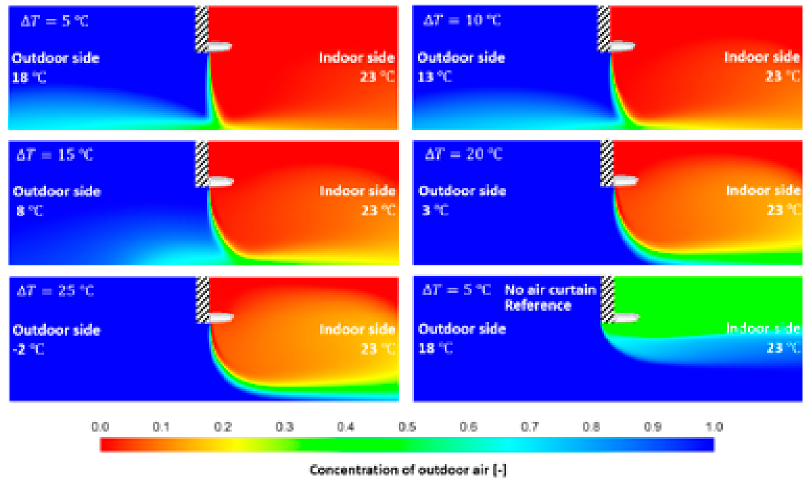


Figure 2 Effect of the variation in cross-jet temperature gradients (5°C ≤ ΔT ≤ 25°C) on air curtain performance. The colors indicate the concentration of outdoor air (dark blue = 100% concentration of outdoor air, dark red = 0% concentration of outdoor air).

Eindhoven University of Technology
ir. **Claudio Alanis Ruiz,**
dr.ir. **Twan van Hooff,**
prof.dr.ir. **Bert Blocken**

References

Biddle B.V. (2016). Velocity measurements from curtain CA2-S-200-W-F at 230V. Internal correspondance.

Cho, H., Kim, K., & Song, J. (2011). Applications of impingement jet cooling systems. In A. Shanley, *Cooling Systems: Energy, Engineering and Applications*. Nova Science.

Emmerich, S., & Persily, A. (1998). Energy impacts of infiltration and ventilation in U.S. office buildings using multizone airflow simulation. *Preceedings of IAQ and Energy 98 Conference*, (pp. 191-203). New Orleans, USA.

Foster, A., Swain, M., Barrett, R., D'Agaro, P., & James, S. (2006). Effectiveness and optimum jet velocity for a plane jet air curtain used to restrict cold room infiltration. *International Journal of Refrigeration*, 29: 692-699.

Frank, D., & Linden, P. (2014). The effectiveness of an air curtain in the doorway of a ventilated building. *Journal of Fluid Mechanics*, 756: 130-164.

Gil-Lopez, T., Castejon-Navas, J., Galvez-Huerta, M., & O'Donohoe, P. (2014). Energetic, environmental and economic analysis of climatic separation by means of air curtains in cold storage rooms. *Energy and Buildings*, 74: 8-16.

Giraldez, H., Perez Segarra, C., Oliet, C., & Oliva, A. (2016). Heat and moisture insulation by means of air curtains: Application to refrigerated chambers. *International Journal of Refrigeration*, 68: 1-14.

Goubran, S., Qi, D., & Wang, L. (2017). Assessing dynamic efficiency of air curtain in reducing whole building annual energy usage. *Building Simulation*, 10: 497-507.

Khayrullina, A., van Hooff, T., Blocken, B., & van Heijst, G. (2017). PIV measurements of isothermal plane turbulent impinging jets at moderate Reynolds numbers. *Experimental Fluids*, 58:31.

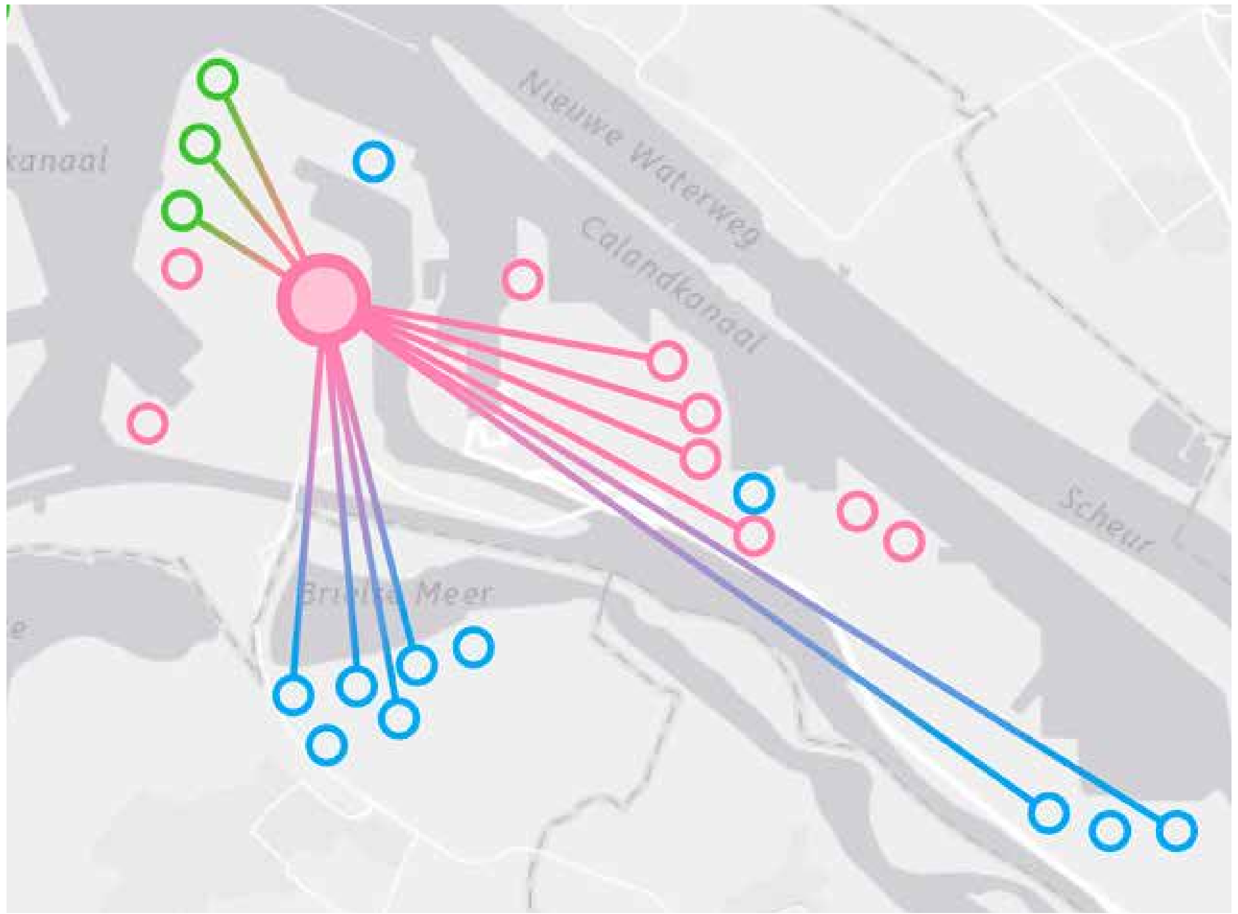
Krajewski, G. (2013). Efficiency of air curtains used for separating smoke free zones in case of fire. *Proceedings of BS2013: 13th conference of International Building Performance Simulation Association*. Chambery, France.

Luo, N., Li, A., Gao, R., Zhang, W., & Tian, Z. (2013). An experiment and simulation of smoke confinement utilizing an air curtain. *Safety Science*, 59: 10-18.

Shih, Y., Yang, A., & Lu, C. (2011). Using air curtain to control pollutant spreading for emergency management in a cleanroom . *Building and Environment*, 46: 1104-1114.

Wang, L., & Zhong, Z. (2014). An approach to determine infiltration characteristics of building entrance equipped with air curtains. *Energy and Buildings*, 75: 312-320.

Zhai, Z., & Osborne, A. (2013). Simulation-based feasibility study of improved air conditioning systems for hospital operating room. *Frontiers of Architectural Research*, 2: 468-475.



ARCHITECTURES OF THE BLACK GOLD

To understand the complex challenges of sustainable energy futures beyond oil and to meaningfully imagine new futures, we need to first understand the extent to which oil is part of our physical environment as well as our mindscapes. We have to understand the historical spread of oil-related industrial, administrative, and retail structures in conjunction with urban planning, policymaking, and architectural design. To help scholars and the general public to track the history, the location along with the spread of petroleum in our built environment and, to explore its impact on our spatial imagination and memory, we have devised both an open access webpage and an interactive augmented reality tool. Our case study is the Randstad and notably the Rotterdam/Den Haag area. Using an average smartphone (or tablet), users can easily retrieve local information about oil and see it superimposed on their own landscape; they can also upload their own stories and information (citizen narratives) to the database. Viewers thus learn how oil infrastructure has shaped the urban form and function of the Randstad. We hope that they will also use these tools to think about the necessity to connect alternative energy futures with interconnected urban spaces.

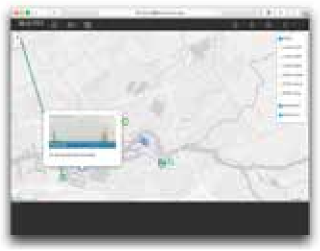
Current computing technologies allow us to connect our readings and interpretations of the built environment to extensive background information. We can retain research data, and comprehensively and coherently, superimpose the data on representations of the built environment. Viewers can directly see where the information comes from or what it refers to. Furthermore, it is possible to establish flexible connections between digital information and what we perceive in reality. Replacing fixed narratives laid traditionally down in written form for readers, these new tools invite viewers to discover or invent new narratives. The augmented reality tool adds three dimensions to what we perceive:

1. A historical viewpoint - It explains the tangible, physical building in front of the observer, revealing its background story: construction dates, alterations, or demolitions; why and how it was made in a certain way; the people involved in its creation and use. It traces the past through the present. Showing what was there before, it allows people to see how and why the built environment has changed.
2. A citizen viewpoint - It makes visible the intangible - commodity flows, financial patterns, and human relations - linking the built environment to its wider uses. The augmented reality tool draws information from a website (www.oilscapes.com) that is itself part of our output; it gives us the opportunity to share research data with others, especially the wider public. Users can not only explore the data with the overview the site affords but also contribute to it by uploading their own data and stories.
3. A tourist viewpoint - It facilitates understanding of the physical landscape through a topical lens—such as energy—while also appealing to curiosity.

The Augmented Reality Tool

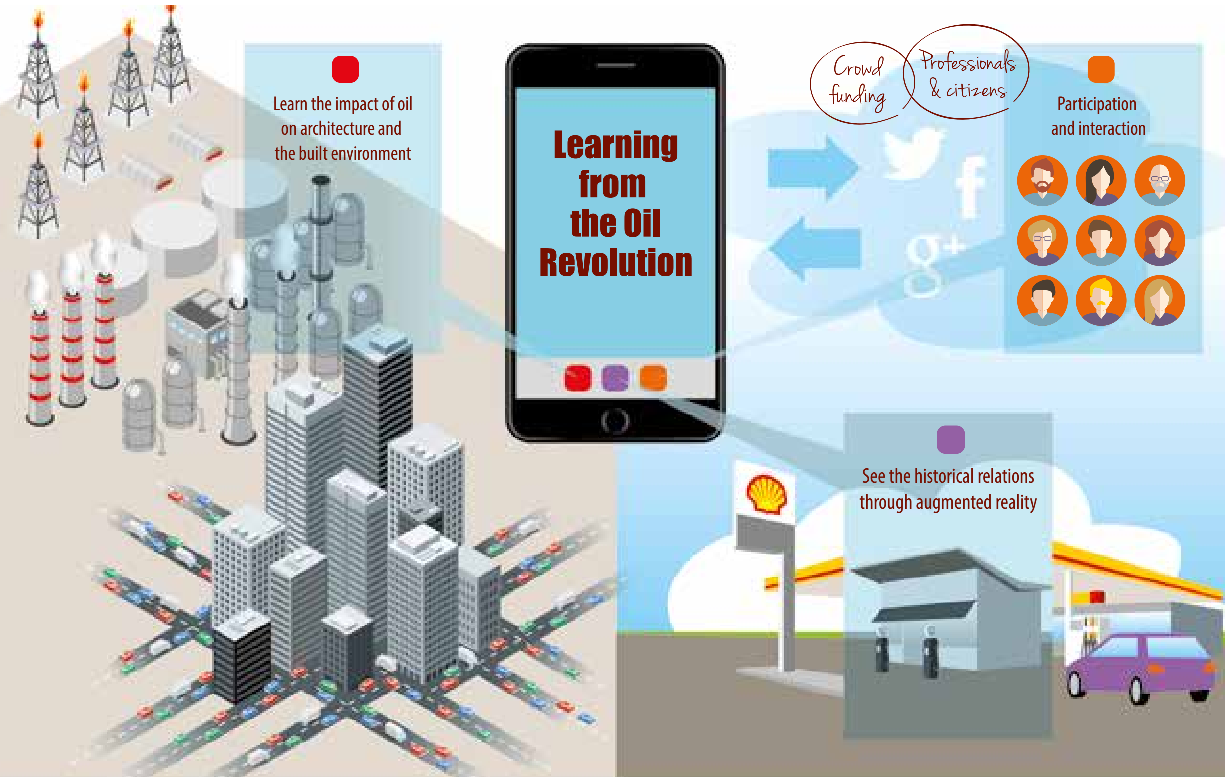
Such a tool must support a challenging combination of overview and detail, and let users make smooth transitions between views of reality and views of multimedia digital information. Even solving these problems, technical issues like the size of smartphone screens and viewing conditions can limit what viewers see. And there are human limitations too. Despite our familiarity with smartphones and daily interaction with their touchscreens, augmented reality is still largely new to most people. Many lack experience with the interfaces in question. So, we have opted for simple interactions and a primarily visual digital content, with texts and diagrams playing a supporting role (e.g. for making transparent transitions from one item to another).

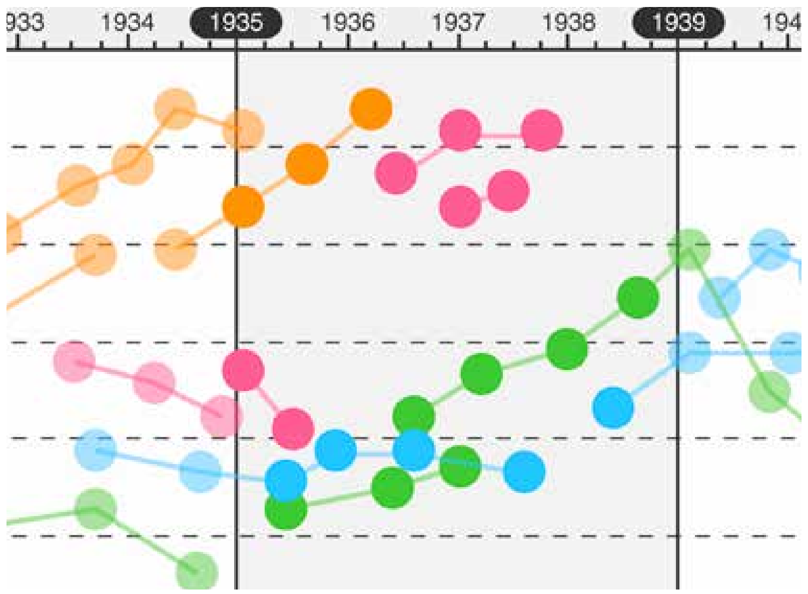
In an early stage, we recognized that these challenges reach beyond the production of computer code alone, and the real trials lie in the user experience. Therefore, the development of the interfaces followed an archetypical user-first idiom. We decided how to program and design the interface itself by making storyboard-like depictions of actions that viewers might take. We visualized the actual geospatial data with a small handpicked dataset, restricted in time and space: roughly 400 oil-related objects from the 1860s to1940 in the Port of Rotterdam and tested it with a small group of users.



Improving the Tool

Then, based on this first experience, we enlarged the geo-temporal search-area to the greater Randstad region between 1860s and 2010, resulting in an updated collection of roughly 6000 historical objects. This time we employed several automated data acquisition strategies, mimicking the rather unbound workings of a crowd-sourced open data platform. In this stage, we realized that systematic cartographic prototyping of the augmented reality layers was needed in order to adequately display large and dynamic crowd-sourced geospatial data, and started closely collaborating with mapmakers at TU Delft. We all learned more about the concurrent and multidisciplinary use and enrichment of data; about color, iconography, and typography in mapping; and about typological groupings, levels of scale, historical time framing, geospatial clustering, and geometric representations. We used these insights to improve the tool, and are working with test users to finalize its design.





Using the Tool

For now, the first version is available to the public. We hope that it helps users gain a fuller understanding of the ubiquity of petroleum in our built environment, and that such understanding will also lead us all to new approaches to sustainable and green energy networks, as well as to new approaches to heritage and its preservation. For example: Once petroleum is in our past, how will we contextualize oil-related structures such as headquarters or gas stations that are part of our heritage, even already added to the national heritage list? The oil pomp Jaknikker in Schoonebeek is already included in the register of national monuments, but will we "preserve" the networked heavily polluted industrial heritage of oil – the storage tanks, pipelines, and drilling platforms, and also the highways? These open access tools provide a unique opportunity for citizens, scholars and planners alike to comprehend the interconnected spatial and cultural aspects of petroleum and to imagine and promote alternative energy futures.

Delft University of Technology
prof.dr.ing. **Carola Hein**,
dr.ir. **Alexander Koutamanis**,
ir. **Seyed Sedighi** PhD,
ing. **Lars van Vianen**

Eindhoven University of Technology
prof.dr. **Bernard Colenbrander**,
ir. **Femke Stout**

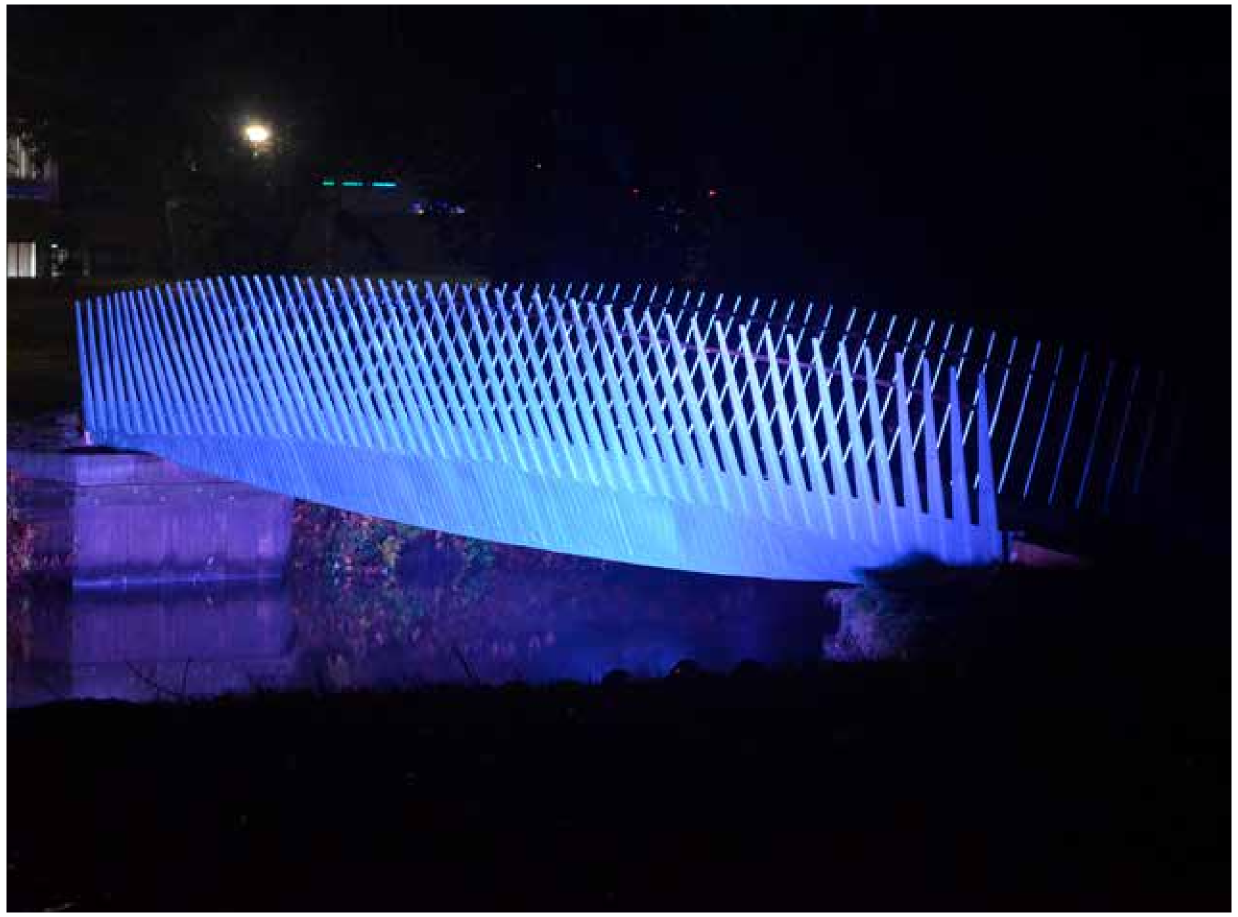


Photo Tom Veeger

BIO BASED BRIDGE

The project aims to design, produce and realise a small, but fully bio-based composite pedestrian bridge at the campus of TU/e. So far, few bio-based building projects have been realised world-wide, but they focused either on non-structural elements or they partially used building materials based on fossil materials. The application of bio-based materials in the built environment is an extremely promising approach towards a more circular economy and a sustainable environment, which is one of the National Science Agenda's themes: "Energy and raw materials: Circular economy". Recent developments have shown that bio-based materials can provide a useful approach for recyclable objects. Until now, fully bio-based primary structural elements have not been used and the applications are limited to experiments with facades components. Building industry clients are generally hesitant to put new technologies into practice without a proof of concept and therefor this pedestrian bridge is a big step forward.

The main goals of the research project on bio-based materials were: investigating options for further reduction in the use of fossil fuels, preventing further depletion of raw materials and increasing options for a transition towards a more circular economy. For the unit Structural Design at the University in Eindhoven: TU/e, the main research question was whether and how these bio-based composite materials could be used in structural loadbearing (bridge and building) applications.
Until recently, bio-based composites have already, sparsely, been used façade applications and, there are some structures with limited bio-based materials known, but a bridge fully made out of bio-based composite materials had not been

realised yet. TU/e (acting as the project leader) submitted the research project proposal at the end of 2015 for the 4TU lighthouse call. The project was awarded in early 2015 and with the other project members: the university in Delft: TUD, as well as the Dutch Centre of Expertise Biobased Economy (universities of applied science Avans and HZ)) and a company NPSP bv, the projected started in early 2016.

The initial ambition was to realise a bridge with a span of about 8 m. This ambition was raised towards realising a bridge of 14 m. This way it became possible to cross the width of the river Dommel at the TU/e campus in Eindhoven. With the help of the TU/e real estate agency a location was found at an already existing small steel footbridge. This way the already existing bridge abutments could be reused.

Design and Elaboration

The bridge, first in its kind, has been made fully out of bio-based materials: Flax and hemp fibres in a bio-based resin and round an internal shape of PLA bio-foam. Obviously the bridge had to fulfil the normal structural requirement in terms of safety and usability, like any other bridge. Also, a normal building permit by the municipality of Eindhoven was required. The research, the design as well as the production and installation has entirely become possible through the enthusiastic collaboration of many students involved in all parts of the project. The project team-members together with students started off in joint design sessions, with generating design ideas in sketches and models. In further sessions, the most promising designs were further investigated and elaborated. In student projects the designs were optimised using Rhino/ Grasshopper programs, materials were tested on strength and stiffness in the TU/e's structural laboratory in order to model the material behaviour as close as possible and to arrive at safe design values of strengths. Using these values as well as other sources the preliminary structural design calculations were made. In a later stage when more information became available simple beam- models were replaced by more complicated Final Element Models (FEM). From the final design the detailed production drawings were made.

Vacuum-Infusion

The chosen production method was Vacuum-infusion. Simply put, this meant that layers of fibres (flax and hemp) were glued around a shape of bio-foam, this was then put in a large bag and brought under a vacuum. This causes a liquid bio-(epoxy) resin to be sucked into the product. This resin has been mixed with a hardener and causing a chemical reaction. With the fibres this in fact becomes the solid bio-composite.

The exo-thermal reaction of the hardener in the resin heaths up the internal foam core. Earlier tests and making a 2 m, 1:1 scale production test model showed that the temperatures could become too high causing the foam core to melt. For this reason, it was decided to work with prefabricated lamellas of 10 mm in the top and bottom flanges of the bridge beam as well as using insulating layers of cork material. Thus, a closed bridge section was created of 20 mm thickness at top and bottom flanges of the beam and only 10 thickness at its web sides. It means that the resulting bridge beam is very light-weight in comparison to other, for example concrete, bridges. The whole bridge including its rather heavy railing weighs 2,6 tons.

To monitor the bridge beam's structural behaviour during its Service Life, glass-fibre sensor technology, called Fibre Brag Grating (FBG), in to the top and bottom flange of the bridge is integrated. Elongation of the glass fibre sensor, caused by a change in temperature or by an external load, causes a shift in the reflected light spectrum that is sent through the glass fibre at the sensor positions. This shift in spectrum is a precise measure for the local elongation and has an accuracy of 1 micrometer per meter.

With students using these techniques the elongations of the 28 sensors is being monitored. Additional load tests static as well as dynamic (Eigen-frequencies, damping behaviour) are carried out.

The earlier mentioned 2 m test model, as well as the final bridge, have been produced at the Avans Composite Laboratory at Spark Rosmalen, Netherlands. The bridge has been produced by Tstudents of 4 different educational levels, from University towards vocational training (TU/e, TUD, Hogeschool Avans, het Koning Willem 1 college and Bossche Vakschool).

Eindhoven University of Technology
ir. **Rijk Blok**,
prof.Dr.-Ing. **Patrick Teuffel**

Delft University of Technology
ir. **Joris Smits**, ir. **Rafail Gkaidatzis**

Centre of Expertise Bio-Based Economy
ir. **Willem Böttger**,
ir. **Alwin Hoogendoorn**

NPSP BV
ir. **Mark Lepelaar**

Avans University of Applied Sciences

HZ University of Applied Sciences

Built at SPARK location in Rosmalen

Results

Finally, the structural strength and safety was tested and proofed successfully in attendance of the Building inspectors of the Municipality of Eindhoven. The load test adding 500 kg/m2 in large water containers was without problems and it also showed the accuracy of the theoretical models in the prediction of the deflections.

With the help of many students and many others involved, the bridge was installed, on time, during the so-called Dutch Design Week event (DDW) in October 2016. Alderman Mary-Anne Schreurs opened the bridge for public use and declared that the city of Eindhoven would like to have a second bridge in the development of their City area "Mariënhage". This project is now well under way, resulting in further research and developments. Research on moisture and creep influences as well the monitoring of the bridge itself are currently being performed.

CAST FORMWORK SYSTEM

CAST Formwork System (CFS) is a concrete formwork system based on CNC milling technology. It enables self-construction in informal areas to build up safe, incremental housing up to four storeys high. Ordinary formwork systems are complex to use, often too expensive for the low- to mid-low income group and only suited to one shape of building plot. The CFS-system is not only cheaper, it can be customized to all shapes of building-plots and is both safe and easier in use.

The Problem

We live in an urban era; the Global Health Organization estimates that in 2050 almost 75% of the world population will live in cities. The biggest urban growth will take place in 'informally built parts of the city', often known as slums. These areas are formed when the government can no longer deal with the rapid growth of the urban population and city inhabitants start constructing their own living quarters. While densification in these ever growing mega-cities is sorely needed, the inhabitants often lack the building knowledge needed to construct safe housing over two stories high. Dangerous situations occur since these self-constructed houses are often not able to withstand the earthquakes and yearly flooding these poorly situated areas are exposed to.

The Goal

The immediate objective is to provide a safe building method in the informal areas of Indonesian cities. These informal areas are called 'Kampung' and are an excellent example of self-build areas, 80% of Indonesian cities consist of these kampungs. They are more than just places to sleep, these Kampung thrive on a very close knit community and are full of economic activities. A governmental top-bottom approach in handling these areas often consists of tearing down the whole Kampung and build high rises in its place. This 'block attack' destroys not only the community but also denies the city inhabitants their economic opportunities. The CAST Formwork System proposes a bottom up approach where the inhabitants can independently build up safe housing in accordance with local practice.

Origins

The company CAST Formwork System (CAST) came forth from the thesis 'Tra-Digital Hybrids' written by Nadia Remmerswaal. In July 2015, she graduated from the Faculty Architecture at TU Delft as best graduate of her year with this thesis. In her graduation project, she delved into enabling safe, self-build constructions in informal neighborhoods, the Kampungs of Bandung, Indonesia.

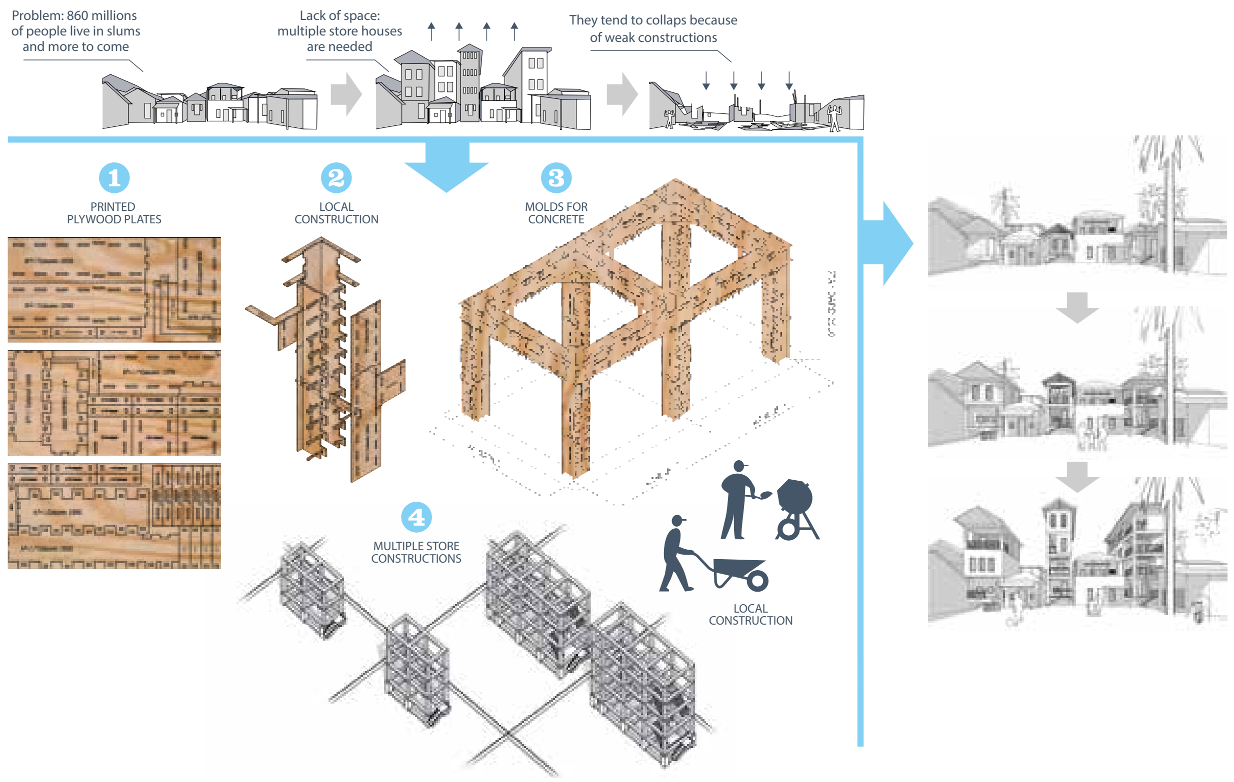
Research shows that 80% of the build environment of Indonesian cities is self-build, in Indonesia this results in 100 million Kampung inhabitants, and it is expected that before 2050 we will see 50 million more Kampung inhabitants. This enormous city growth is not limited to Indonesia, but will happen in mega-cities worldwide. These DIY areas are prone to earthquakes and flooding, and residents often do not have enough building knowledge to build sustainable structures to withstand these natural disasters. After witnessing this in the cities of Indonesia, Remmerswaal tried to find a technical solution in her architectural graduation to enable safe self-construction in these areas.

After graduating Remmerswaal sought funding in the form of scientific financing and participated in several competitions to develop the project further. The project won the ASN Bank World Prize "Veiligheid & Sociale cohesie", prize money €8000, the STW Open Mind funding, €50,000 and the 4TU Lighthouse funding, €50,000. The project has been renamed 'CAST Formwork System', CAST an abbreviation of 'casting concrete' and Remmerswaal started developing the project in February 2016. The objectives of the project are to create both a workable prototype and a workable revenue model. Both are be completed in February 2017 when the project financing ends.

The Technique

CAST Formwork System is a formwork system based on CNC milling technology. The CAST system makes up the mould in which the concrete can be cast. The resulting concrete frame forms a durable structure and safe concrete skeleton. The formwork is specifically designed for self-build areas, to be used by residents themselves. The system is made from special wood: Betonplex, this hardwood triplex has a smooth, very durable coating that makes de-casting the formwork easy. Betonplex is being produced locally in Indonesia. The elements are never bigger than 1,5 meter, and can be easily transported into the Kampung using a handcar. It is designed to be as simple as possible, so that it can be put together by people with limited construction knowledge.

After the assembly of the formwork, the concrete is cast and when dry the formwork can be reused a minimum of 8 times. Normal formwork systems are often complex to use, need cranes or trucks to be transported or assembled, are too expensive for the low to middle-low income group in self-construction areas and only suitable for one form construction plot. CAST strives to be an inexpensive alternative that is easily adapted to multiple building plot configurations. Since not



a single house in the Kampung, or self-build areas around the globe for that matter, are equal, this is an essential important aspect of the system.

With CAST Formwork System it is safe to build up to multiple levels, right now this is often impossible, inadequate construction knowledge prevents the buildings to reach over 2 building stories. With the CAST-system, it would be possible to expand the dwelling in an incremental manner: the first year the foundations and first story is constructed, and when inhabitants have gathered sufficient funding a second story can be constructed several years on. This incremental building method is essential as these informal neighborhoods often lack the financial resources to construct a four-story house all at once. This incremental construction method makes it possible for a household to spread the investment over several years.

The Next Step

In December 2016, a CAST-Formwork prototype has been tested at the Green Village in Delft. A concrete frame of 3 x 7 x 3 meter has been realized within two weeks. While some technical adjustments have to be made, the team considers the test a great success. The next step is to do more local testing in Indonesia in January 2017, and to present the formwork at the 'Week van de Bouw' in February 2017. A pilot project is being developed in Bandung Indonesia, if sufficient funding is found, 6 pilot homes will be built with the CAST Formwork System in May 2017.

Delft University of Technology
ir. **Nadia Remmerswaal**,
Dr.-Ing. **Marcel Bilow**

Eindhoven University of Technology
dr.ir. **Faas Moonen**, ir. **Rijk Blok**

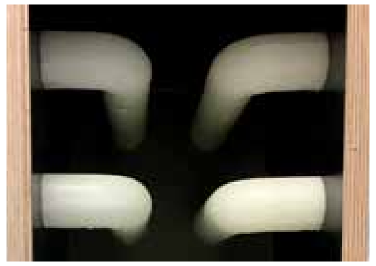
Jongeneel

Cementbouw

Van Gelder

GreenVillage

Riset 8 kota Indonesia



CONVECTIVE CONCRETE

Convective Concrete is about a research-driven design process of an innovative thermal mass concept. The goal is to improve building energy efficiency and comfort levels by addressing some of the shortcomings of conventional building slabs with high thermal storage capacity. Such heavyweight constructions tend to have a slow response time and do not make use of the available thermal mass effectively. Convective Concrete explores new ways of using thermal mass in buildings more intelligently. To accomplish this on-demand charging of thermal mass, a network of ducts and fans is embedded in the concrete wall element. This is done by developing customized formwork elements in combination with advanced concrete mixtures. To achieve an efficient airflow rate, the embedded lost formwork and the concrete itself function like a lung.

The use of thermal mass is usually considered as an effective strategy for achieving energy efficient building designs with high thermal comfort levels. This is normally done by applying construction types with high thermal storage capacity (e.g. concrete) on the inside of the thermal insulation layer. Such heavyweight constructions have a slow response time. This thermal inertia helps to flatten temperature peaks, but the slow response is not advantageous at all times. Due to a lack of control possibilities regarding when and how much energy to exchange between interior zones and the constructions with thermal mass, these dynamic effects may also increase heating and cooling energy demand during intermittent operation or can cause unwanted discomfort, either due to too cold surface temperatures when the building is already occupied on winter mornings, or because the accumulated heat can sometimes not be sufficiently released, leading to potential indoor overheating issues in summer. Another shortcoming of thick concrete slabs is that only a small part of the heavyweight material (usually the first few centimeters) plays a role in storing thermal energy effectively. This is a missed opportunity.

Water as Transport Medium

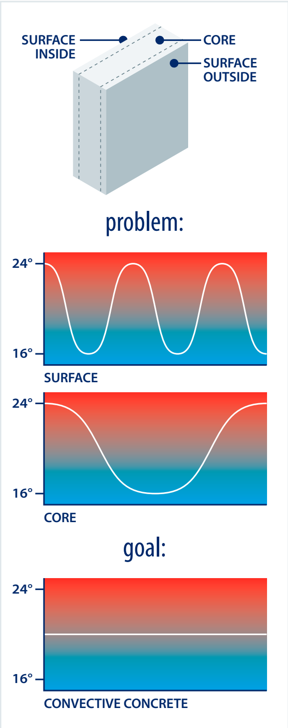
Convective Concrete initially targets the residential building market. The goal is to mitigate residential overheating during summer periods by reducing the temperature of constructions through active heat exchange between the building construction (hollow-core concrete slabs) and cool outside air at night. Even though air has a relatively low volumetric heat storage capacity compared to e.g. water, it is used as a transport medium in this project, because of:

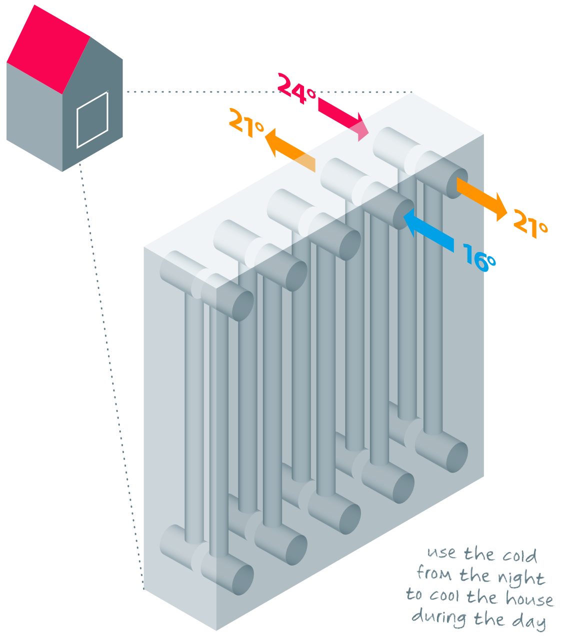
- Its widespread availability at favorable temperatures
- Can be combined with earth tubes
- Easy construction and installation process: plug-and-play
- Provides standalone elements that do not need to be connected to additional systems
- Can function passively without mechanically forced convection due to the buoyancy effect
- No risk of leakages, punctures or frost damage
- Low weight and therefore less structural requirements

To accomplish the on-demand charging of thermal mass, a network of ducts with attached fans, needs to be embedded in the concrete wall element. The fans act as back-up to the buoyancy effect to ensure a sufficient amount of air flowing through the wall. This is done by developing customized formwork elements in combination with advanced concrete mixtures.

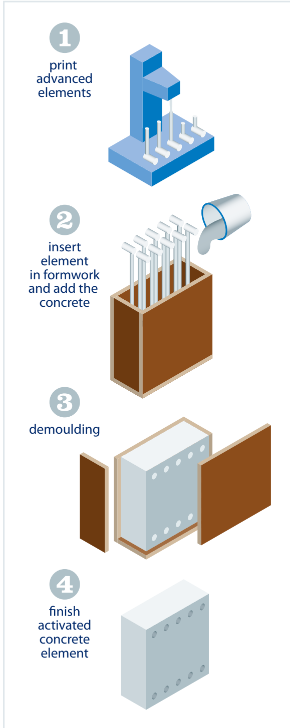
Additive Manufacturing (AM) is researched, because it is a good method for this kind of rapid prototyping. Customized and free-form parts can be produced easily. AM of lost formwork differs from the approach of direct concrete printing, but allows for a traditional processing of the concrete itself. To benefit most from AM as production technology, the free-form and customized parts needed for the Convective Concrete are printed in wax, using Fused Deposition Modeling (FDM), an AM process based on material extrusion, that can be melted after the concrete is hardened. The building volume and resolution of FDM printers can be adapted to the desired size and layer thickness easily. However, for the first prototypes wax casting was used.

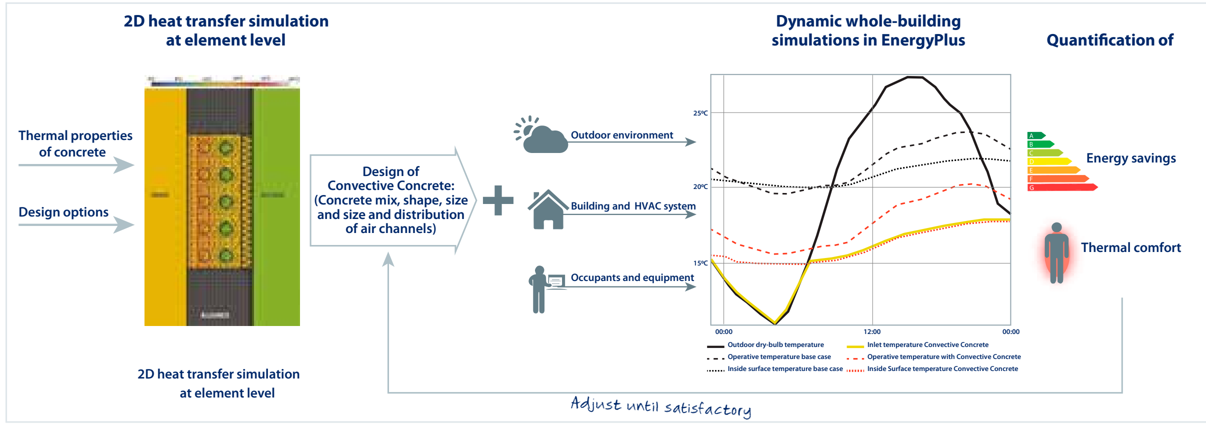
To achieve an efficient convective flow, the embedded lost formwork and the concrete itself should function like a lung. The convection takes place with separate pipes on both sides of the concrete's core to increase the charge/discharge of the thermal storage process with help of fans, in the event of lack of buoyancy effect and with the help of valves, to control when the slabs are ventilated. There will not be any openings through the slabs themselves, because that would cause thermal bridges. The concrete mixture with matching characteristics (density, porosity and lambda value) will be fabricated on the basis of input from computational simulations.





Temperature equalizer & energy storage





Delft University of Technology
Dennis de Witte MSc.,
prof.Dr.-Ing **Ulrich Knaack**

Eindhoven University of Technology
Marie de Klijn-Chevalerias MSc.,
ir. **Roel Loonen,**
prof.dr.ir. **Jan Hensen**

G.tecz
Dr.-Ing **Gregor Zimmermann**

Results

As soon as the outcomes of the simulations match the physical models, parametric models can be designed, after which optimized internal formwork for the Convective Concrete can be printed and the façade and internal walls can be applied in the built environment. The final product can be in the form of a prefabricated concrete slabs, but also in the form of the inserts itself that is are placed embedded in the on-site built formwork.building volume and resolution of FDM printers can be adapted to the desired size and layer thickness easily. However, for the first prototypes wax casting was used.

To achieve an efficient convective flow, the embedded lost formwork and the concrete itself should function like a lung. The convection takes place with separate pipes on both sides of the concrete's core to increase the charge/discharge of the thermal storage process with help of fans, in the event of lack of buoyancy effect and with the help of valves, to control when the slabs are ventilated. There will not be any openings through the slabs themselves, because that would cause thermal bridges. The concrete mixture with matching characteristics (density, porosity and lambda value) will be fabricated based on input from computational simulations.

As soon as the outcomes of the simulations match the physical models, parametric models can be designed, after which optimized internal formwork for the Convective Concrete can be printed and the façade and internal walls can be applied in the built environment. The final product can be in the form of a prefabricated concrete slabs, but also in the form of the inserts itself that is are placed embedded in the on-site built formwork.

DOUBLE CURVED 3D CONCRETE PRINTING

It is no secret that there have been some great advances in the realm of concrete additive manufacturing. However, one of the major drawbacks of this fabrication technique is that the elements must be self-supporting during printing. While most other additive manufacturing materials can overcome this by using a secondary printed support structure, alternative strategies must be developed for materials such as concrete.

This 4TU project explores the possibilities of combining concrete additive manufacturing with a temporary support surface. By printing on a free-form surface, more intricate geometries can be realized. Several potential applications have been outlined, however the principle focus is combining concrete additive manufacturing and casting. The end result is a partially-printed pavilion using a completely digital design-to-fabrication workflow.

Although additive manufacturing (AM) is a fabrication technique which has been around for the past 20 years or so, it is only now that we are starting to see its applications emerge into the built environment. Whilst metals, plastics and other composite materials are also being explored for their use in the Built environment, it is concrete that shows great potential for large-scale additive manufacturing. Concrete Printing techniques already allow for the rapid fabrication of large-scale structures with minimal material waste, as already exhibited by Winsun and the fabrication of 1,100 Sqm Apartments in Jiangsu, China.

Whilst this does indeed allow for the rapid fabrication of concrete structures, most elements printed remain as 2.5D rather than 3D. This is due to the fact that extruded material must be self-supporting during printing in order to avoid collapse, imposing somewhat of a geometrical restriction. Most other printing materials can overcome this by printing a temporary support structure, however this is not the case with fluid materials such as concrete. Instead, a temporary surface is proposed as a means of support to printed concrete.

The adaptable mould developed at TU Delft served to provide such a surface. Consisting of a silicone surface connected to a bed of adjustable pins, double-curved surfaces can be produced in a similar fashion to milled surfaces. The main difference being that no material waste is generated since new surfaces are defined by adjusting the pin-bed. Prior to the 4TU Project, this system was used for casting free-form concrete panels. The combination 3D concrete printing and an adaptable mould resulted in a hybrid manufacturing technique consisting of two complimentary fabrication techniques.

Three Potential areas of research were identified through this combination. Firstly, the potential for fully-printed concrete panels. For this, It is proposed to use differential growth algorithms to generate print paths over any given surface. The second potential identified was the printing of structural ribs following stress-lines to provide reinforcement to panels. However, the chosen theme was a combination of 3D Printing and casting concrete. In this, complex geometries are defined by printing a boundary into which concrete is cast. The advantage to this approach is that complex, free-form concrete panels can be realized without the need for complicated moulding systems.

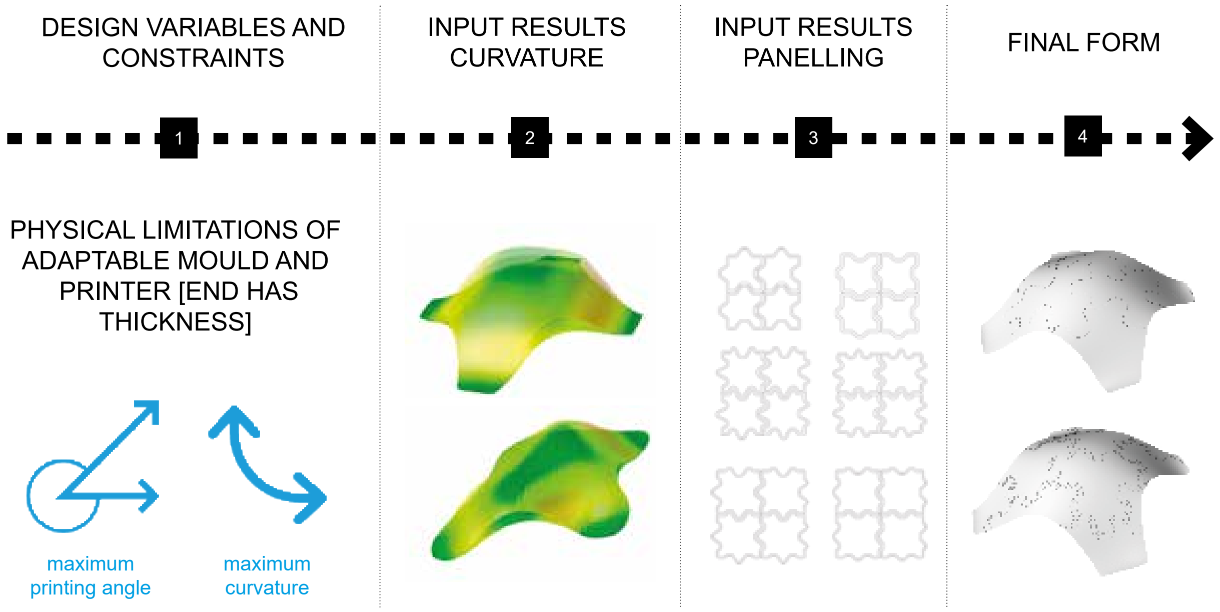
Design Overview

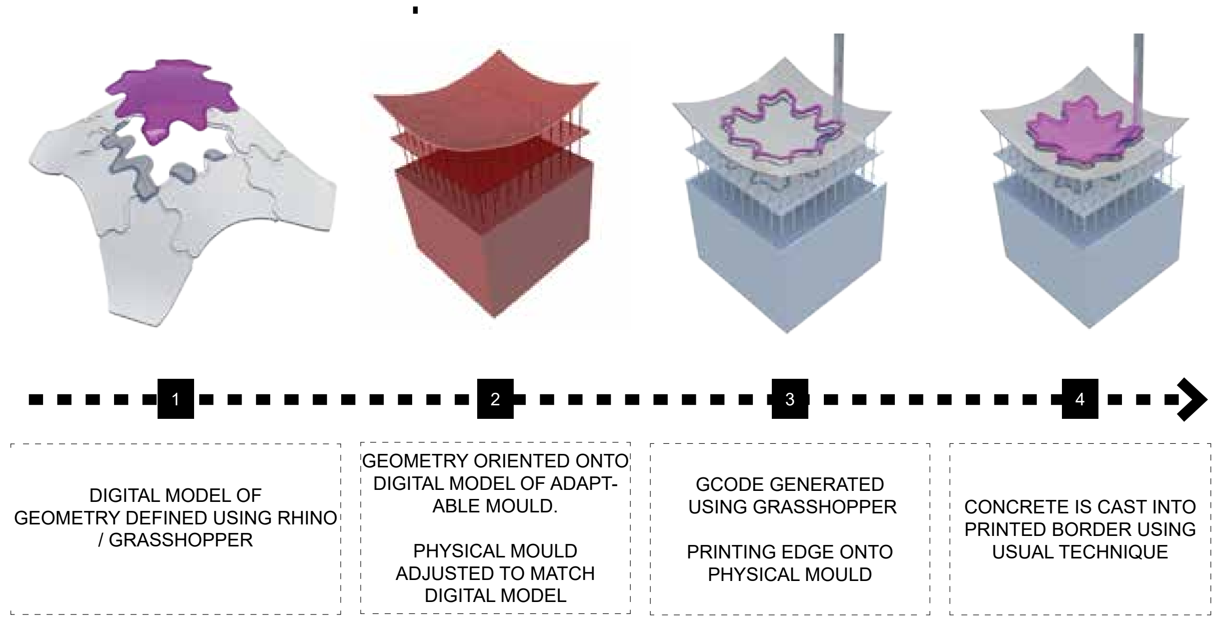
In order to study the proposed manufacturing concept, a shell structure consisting of complex interlocking geometry was designed and printed. The basic principle of realizing the design consists of first creating a digital model of the structure using parametric design tools. Each individual panel is then digitally oriented onto an adaptable mould and G-code is generated by dividing splines that define the perimeter of the object. Once the physical mould is adjusted to match the digital mould, the Gcode is sent to the printer and the geometry is printed. Finally, concrete is cast into the printed shape and left to cure for 24 hours after which it is demoulded.

Fabrication Process

Both the 3D Printer and adaptable mould have their own set of physical limitations. Thus, a number of variables and constraints were set by studying the two technologies. Firstly, the maximum slope angle on which concrete can be printed was found to be 40 Degrees, after which material had a tendency to curl up and distort. This value was used to limit the maximum curvature of the form-found shell structure. Due to the printer's incapability to print right angles, a minimum turning radius was also determined and was used to generate the tessellations for printed geometry. The end result is a 2.5 m x 2.5 m shell with a maximum slope of 35 degrees and minimum turning radius of 150 mm, consisting of a total of 9 Print-And-Cast panels.

In order to have a design process which consists out of one single file from design to fabrication, a custom g-code generator was created using Grasshopper 3D. This was also necessary because slicing techniques used in traditional additive manufacturing could not be used since a later-wise approach was not used. Instead, the geometry is defined as a spline and is divided into a number of points depending on curvature of the curve. These points are then expressed in terms of their relative co-ordinates and communicated with the Printer. An additional bespoke script was generated to take into account collisions of the Printer Nozzle with the Surface.





Delft University of Technology
dr.ir. **Roel Schipper**,
Chris Borg Costanzi MSc.

Eindhoven University of Technology
dr.ir. **Freek Bos**,
Zeeshan Ahmed MSc.,
Rob Wolfs MSc.

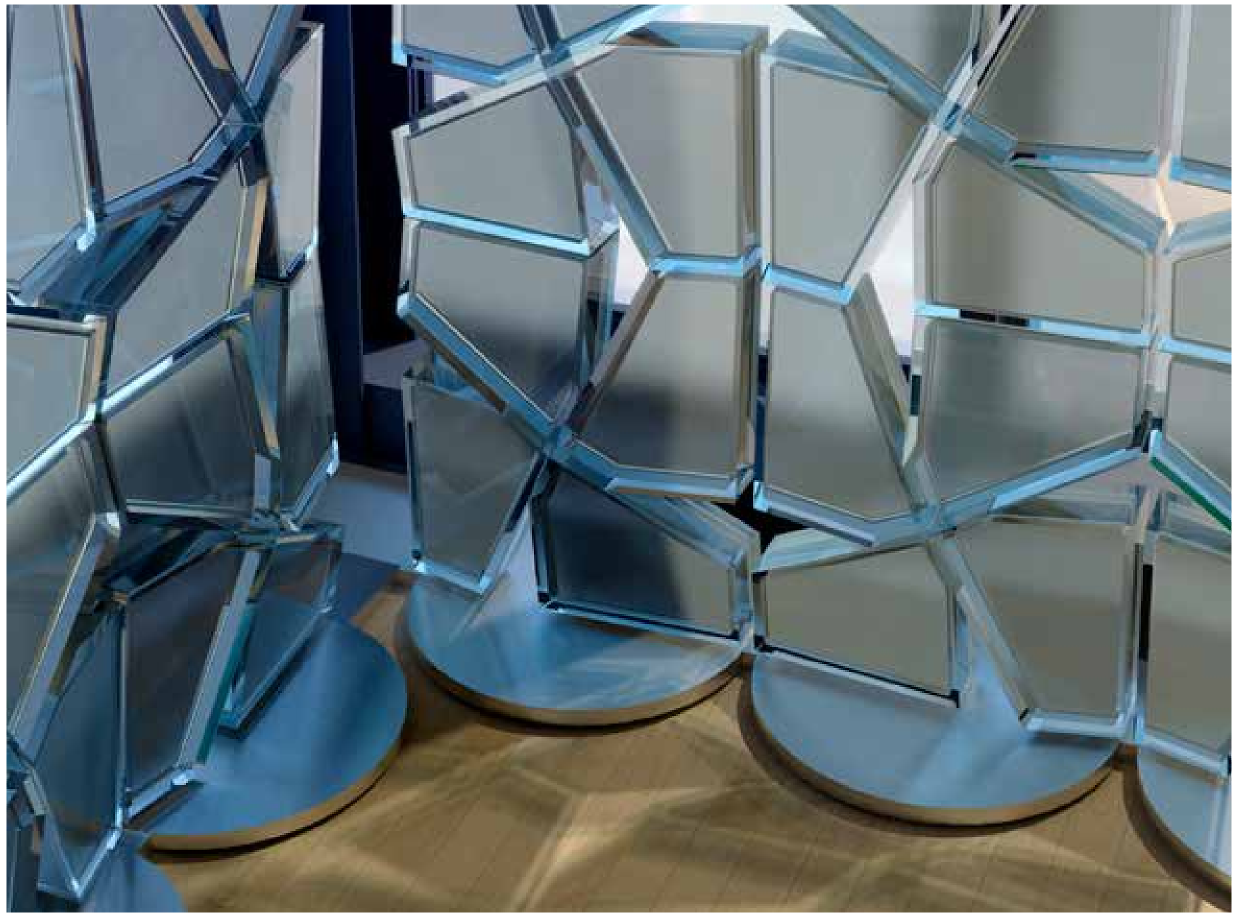
This was required because printing was not done perpendicular to the surface meaning that the physical nozzle had a tendency to collide with steep surfaces. The way this was corrected was by determining the intersection between the nozzle and surface at every co-ordinate and raising the point such that no intersections occurred. The corrected print path is then defined by interpolating the raised points which is then converted into G-Code.

Final Structure

The final structure is printed in a single print pass taking approximately 20 minutes to complete as shown in the image below. After the individual panels are printed, plasticizer is mixed in with printed concrete and cast inside the panels. These are left to cure for 24 hours and demoulded as an inverted shell structure. This is later temporarily propped up and held together through mortar joints.

Challenges and Conclusions

The project was limited to a relatively small 2.5 m x 2.5 m shell structure and the geometries printed were kept relatively simple to focus on refining the design process. However, given that the physical constraints of the printing process have been established it is easily imaginable that scalability and increase of geometrical complexity can be achieved if boundary conditions are maintained. Moreover, the project focused on combining printing and casting, however other directions such as generating print paths which follow stress-lines could serve as future areas of research using the same basic design process.



DOUBLEFACE

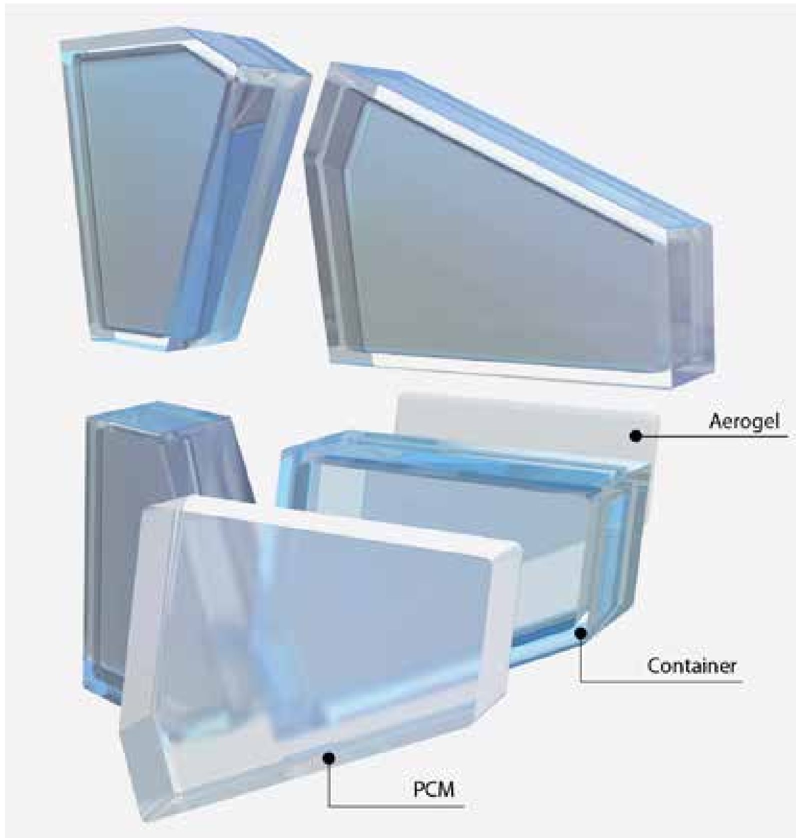
The DoubleFace project aimed at developing a new product that passively improves thermal comfort of indoor and semi-indoor spaces by means of lightweight materials for latent heat storage, while simultaneously allowing daylight to pass through as much as possible. Specifically, the project aimed at designing and prototyping an adjustable translucent modular system featuring thermal insulation and thermal absorption in a calibrated manner, which is adjustable according to different heat loads during summer- and wintertime. The output consists of a proof of concept, a series of performance simulations and measurement and a prototype of an adjustable thermal mass system based on lightweight and translucent materials: phase-changing materials (PCM) for latent heat storage and translucent aerogel particles for thermal insulation.

The system is based on an innovative approach to thermal principles of Trombe walls. As compared to traditional Trombe walls, the system is about five times lighter than traditional Trombe walls to avoid structural overloads in buildings; is translucent in order to benefit from daylight; and is adaptive in order to calibrate the thermal effects.

Lightness and translucency are achieved by means of the applied materials. Instead of using heavy and opaque materials like concrete, a novel application of PCM and aerogel is proposed. Several products and technical systems are currently available on the market for applying PCM by integrating them into walls, containers, or ventilations systems or in facades. Double Face proposes a system based on interior design elements, taking advantage of the dynamic behaviour of

PCM as well as its appearance. As such, the system is also meant to contribute to aesthetical design criteria in the design of interiors. The elements are translucent; are meant to be located in front of a (full) glass façade, where the largest heat impact from outside happens to be; and can be developed into various design options for new buildings as well as retrofitted into already existing buildings. Additionally, the system is adaptive to enhance the thermal benefits. Exposing thermal mass to winter solar radiation (passive heat gain) and protecting it from the summer one (passive cooling) and therefore acting as thermal buffer. This happens by rotating the elements towards the source of incoming heat or the sink for heat release. In winter, the PCM side would face the exterior and be thermally charged during the day by the low winter sun. During night times, oriented towards the interior, it releases the accumulated heat. In summer, during the day in combination with external sun shading, it would store the heat from interior heat loads and during the night release this heat to the outside environment by means of night ventilation, thus acting as a cooling plate.

The research process started with a wide inventory of existing PCM; an analysis of their properties; and a consequent short-list of selected materials. For each of the selected PCM, digital simulations were conducted to analyse the thermal behaviour. They were conducted for single layers of PCM in various thicknesses; and for combinations of two layers, one of PCM in various thicknesses and one of translucent insulation, also in various thicknesses. The translucent insulation was simulated as a layer of Aerogel; and as a system of cavities trapping air within a translucent 3D printed material. Based on the digital simulations, the system of layers was pre-dimensioned for a total thickness of 7cm (5 cm PCM, 1 cm aerogel and 1 cm container wall thickness). Several samples (17x17x7cm) were made for a number of selected PCM. These samples were tested in the laboratory for Building Physics at Eindhoven University of Technology for their thermal behaviour; and at Delft University of Technology for their light transmittance. The measurements



allowed for fine-tuning the dimensions as well as for narrowing down the list of selected materials. As a result, PCM thickness was reduced to 4 cm. Furthermore, using the measured properties as input, simulations of the thermal behaviour of a standard room equipped with this Trombe wall system were run in DesignBuilder to study several variations including PCM layer thickness, insulation layer thickness, extra cavities and percentage of holes in the wall. These simulations showed that an opening percentage of roughly 10% was ideal for this Trombe wall system. Because of the limitations of simulating the rotation of the wall panels, a new simulation model was developed in Matlab/Simulink. These new simulations, which included the rotation, showed that the adjustable Trombe wall system leads to an energy reduction of roughly 40% as compared to the 'no Trombe wall situation'.

Parallel to the research, several design alternatives were drafted, based on the thermal principles. For this project, one design option was chosen to be developed and prototyped. The option shows the potential of exposed technical systems contributing to aesthetical design criteria within interior design, while remaining within feasibility constraints to realize a prototype within the timeline of the project. To realize the prototype, the translucent container for the layers of PCM and insulation, additive manufacturing was considered initially, to cope with the complexity of the form. A number of tests were made by 3D-printing translucent PLA and PET via the rather cost effective filament fused deposition modelling (FDM) method. However, considering the challenge of obtaining translucent parts that have high structural strength and maximum light transmittance without the need of falling back to expensive 3D printing techniques (like Stereolithography), additive manufacturing was later used only to produce moulds to cast transparent resin, in order to get a more glass-like appearance. An option for a laser-cut transparent sheet of Perspex was developed, leading to satisfactory results as well.

The thermal behaviour of the prototype is now being measured using heat-flow sensors and thermocouples at Delft University of Technology. Additionally, further performance simulations are being run in order to model the behaviour of the modular and adaptive system under different climate conditions and in various room environments. Current simulations include fine-tuning of the rotation schedule of the elements to orient the insulation according to contingent conditions (day/night – winter/summer).

The ambitions of the team include tuning this prototype and exploring other design alternatives, for which further development and testing are intended. Several companies have been contacted during the process especially regarding existing PCM and their architectural applications.

Delft University of Technology
dr.Arch. **Michela Turrin**,
dr.ir. **Martin Tenpierik**,
ir. **Paul de Ruiter**, ir. **Winfried Meijer**,
dr.ir. **Willem van der Spoel**,
Carlos Alfredo Chang Lara

Eindhoven University of Technology
dipl.-ing. **Florian Heinzelmann**,
prof.Dr.-Ing. **Patrick Teuffel**,
ing. **Wout van Bommel**

ENERGY EFFICIENT FACADE LIGHTING

The project set out to proof that a conventional optical fibre lighting system for highlighting the structure of a façade can be operated more energy-efficiently through the substitution of the projector using a metal halide reflector lamp by a laser. This is investigated by looking into the photometric assessment of such systems as well as the electric power draw during operation. In preparation for a potential exterior demonstration installation, an additional focal point of the research was the design and testing of a weatherproof case that provides protection to the laser and the ballast. The final stage brought the different aspects of the research together and resulted in a temporary experimental setup (pilot installation) to showcase the validity of this novel approach.

Throughout the project there was active communication between the partners. Meetings took place in Eindhoven, Delft, and Den Haag. At the TU/e two students were recruited to participate in the research project, and at both universities the possibilities for demonstration projects were explored. During the discussions, ideas for details on the overall approach and the setup were developed. The brainstorming continued with the students at their regular project update meetings. They developed the research questions and mapped out their approach in a measurement plan. The student project results were presented at an intermediate workshop and to the project partners.

The weather proofing of the box is being tested for its performance under various exterior conditions, using a climate chamber, by measuring: the interior temperature in the box, the humidity in the box, and the protection against simulated precipitation (snowfall and rain).

After energy performance determination, the photometric assessment focused on two main sets of measurements; illuminance measurements indicating the relative luminous flux coupled out from the fibre and luminance measurements under different observation angles.

The illuminance measurements were carried out along the fibre as well as around the fibre. This produces an indication over the attenuation of the extracted light and the uniformity of the light extraction. The illuminance at a defined and constant distance is a measure for the relative luminous flux leaving the fibre. In addition to that, the luminance from different observing directions was recorded to evaluate the expected brightness perception. The photometric assessment was done for three laser types: red (= 655 nm), green (= 532 nm), and blue (= 447nm).

Power Consumption Measurments

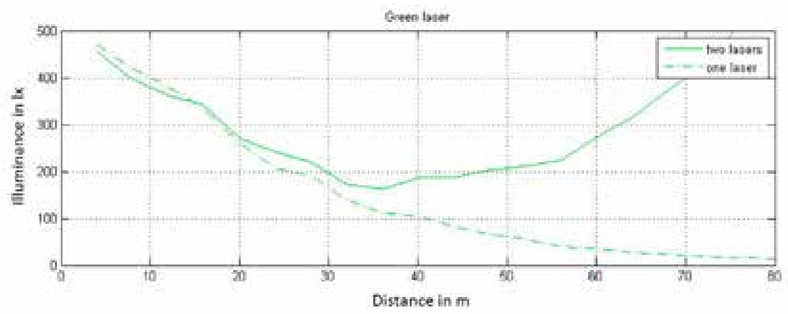
A BL Innovative Lighting fiber is connected to a metal halide (MH) lamp of about 190 W; either on one or two sides of the fibre. Currently, the maximum commercially available length of this fiber is 80 meters, and would require at least four MH lamps to light the full fiber length, with a total energy consumption of 764 W. However, if a MH lamp were to illuminate the fiber from a single end the maximum lenght would be about 13 meters (including visible light loss). With the laser installation, the power consumption over the first 15 minutes after starting the laser was recorded. The results for the three laser types tested are showing a stabilized power draw for the red, green, and blue laser of 59 W, 71 W, and 54 W respectively. The difference in power consumption of the least efficient laser system (2*71 W) compared to a system lit with MH lamps over a comparative fiber length of 80 meters would be five times lower (142 W vs. 764 W), resulting in a savings of approximately 80%.

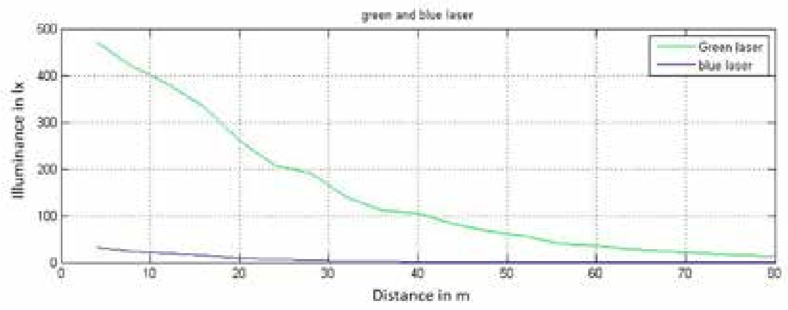
Photometric Measurements

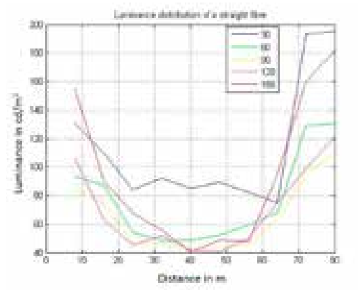
The illuminance was measured at a constant distance from the fibre. This was achieved using a device that was designed and built for this purpose. It can wrap around the fibre and holds the photo element in place. The measurement distance was approximately 1 cm to get the maximum dynamic range. The illuminance measurements are an indicator for the relative luminous flux leaving the fibre. Luminance measurements have been taken under different observation angles around a measurement point. The results give an indication on the brightness perception when viewing the installation from different positions. As a rule of thumb, differences in brightness occur when the luminance difference is approximately one order of magnitude.

Measurement along the Fibre

The measurements along the fibre show that the relative luminous flux coupled out is attenuating over the length of the fibre. The data for a system fed by one laser shows that the relative luminous flux drops by one order of magnitude at a distance of approximately 55 m. A fibre system that is fed by two lasers shows the expected symmetric behaviour. The minimum occurs in the middle of the fibre. There the relative luminous flux is approximately 40% of its initial value. The measurements for a one-laser system can be mirrored to calculate the relative luminous flux along the fibre. The calculations results match the measurements very closely.







Measurement around the Fibre

As a measure for the uniformity in all directions, the illuminance was measured on the four spots around the fibre every 8 m along the fibre (0, 90°, 180° and 270°). The most noteworthy non-uniform light extraction can be observed at the beginning of the fibre. This is likely caused by slight misalignments of the laser axis and the axis of the fibre that are believed to cause non-uniform light losses at the beginning

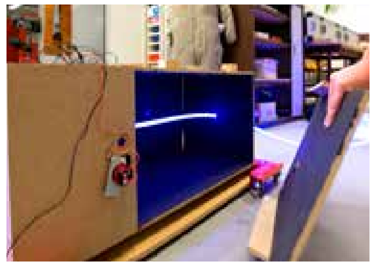
Luminance Measurements

The luminance measurements were taken for two situations: the fibre being fed by one laser and the fibre being fed by two lasers.

As expected, the luminance drops along the length in a similar manner as the relative luminous flux. This effect is reduced in a system fed by two lasers. The luminance is relatively similar for all viewing angles (ranging from 30° to 150° with 90° indicating the surface normal). For a two-laser setup, the minimum luminance drops from approximately 200 cd/m2 to approximately 40 cd/m2. This drop is not leading to a perception of brightness difference according to the rule of thumb mentioned earlier. The laboratorymeasurements indicate that no visible difference along the fibre system would be noticed.

Temperature Dependence

According to the manufacturer's data sheets, the laser systems consisting of a power supply box and the laser module itself need to be operated in ambient temperatures between 10°C and 35°C. A few experiments investigated the influence of the ambient temperature on the light output. The first measurement series looked at the system's performance when ramping up the ambient tem- perature slightly beyond the upper boundary of the recommended temperature range and letting it cool down afterwards. The illuminance measurements indicated the impact on the overall light output. The ambient temperature in the upper part of the recommended temperature range has no significant impact on the light output.



Eindhoven University of Technology
prof.Dr.-Ing.habil. **Alexander Rosemann**, dr. **Myriam Aries, Wies Westerhout, Mitchel Hoos**

Delft University of Technology
assoc.prof.dr. **Truus Hordijk**

Lighting designer
ing. **Rienk Visser**

BL Innovative Lighting - Vancouver
Betty Lou Pacey

Normal operation within an enclosure can often lead to a fluctuating ambient temperature. Such a temperature profile was simulated in the laboratory and also leads to no significant changes in light output. After the lighting system is stabilized, the illuminance values ranged between 55 lx and 56.5 lx which corresponds to a maximum variation of 1.1%.

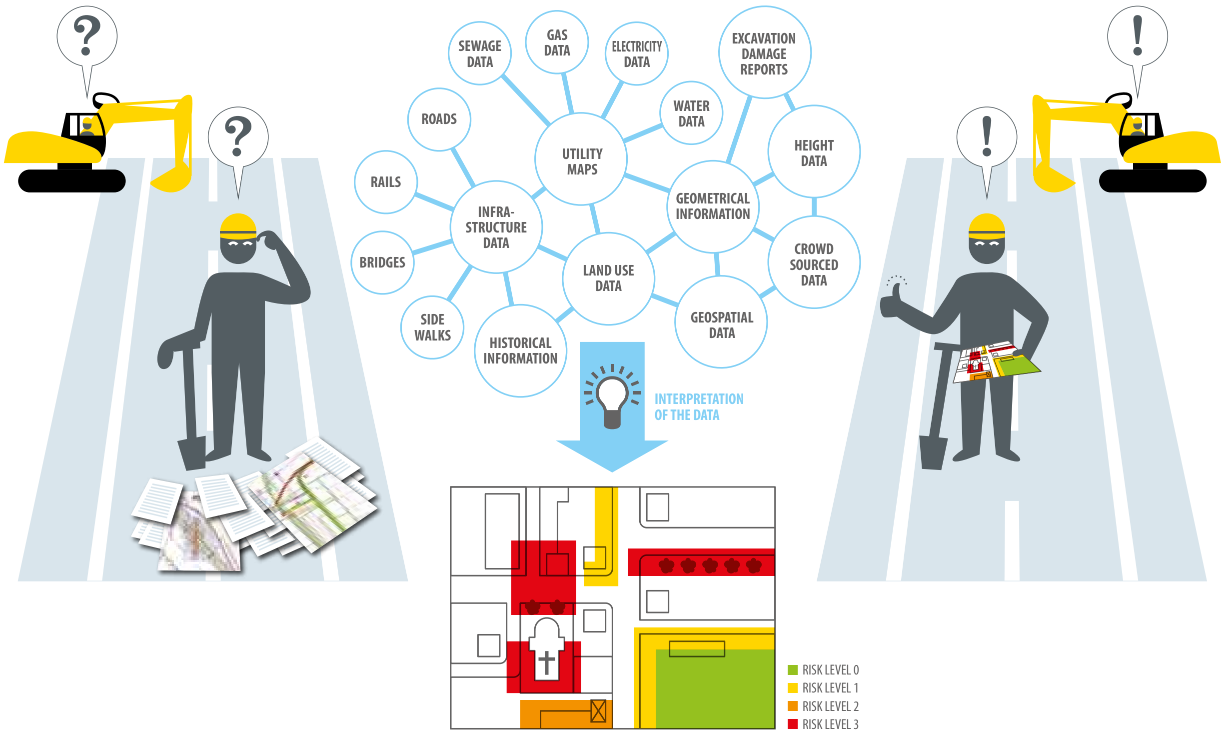
Pilot Installation

A working prototype of the laser/fibre system has been demonstrated on the roof of the Vertigo building on the TU/e campus in December 2014. The 80 m long fibre was installed along the inside and outside of a roof rail resulting in a 40 m long light installation that could be seen from the building as well as from the ground.

80% Reduction of Energy Consumption

The results of this project show that the fibre system fed by lasers is a feasible technology to highlight facades of buildings. The photometric data shows that the system can be operated in such a way that no noticeable brightness differences can be sensed along the fibre. The energy consumption of the lasers are much lower compared to the conventional solution, resulting in a savings of at least 80%. This means that the investigated system is an adequate energy-efficient alternative to conventional fibre lighting systems.

Recommendations for the future include following technology developments to see if such laser systems can be reduced in size for a better integration into the overall system. The current laser system was not developed for a fibre lighting system but rather for measurements/experiments on optical benches. Some of the features and requirements that are currently part of the product may not be required for usage in combination with fibre optics. This can lead to a reduced size and cost for a laser system that would positively impact the economics of real installations.



EXCASAFEZONE

Excavation work takes place almost continually in most cities around the Western hemisphere. Many cities are already full of infrastructures, buried networks, and street furniture, so excavation work is not without any thread to the operator and surrounding environment. Small construction sites, for example, are often constrained by operating infrastructure on surface level and underground. Although different agencies and network owners have information about the location of the objects that put excavation work at risk, this information is not centralized. Different organizations manage location information of buried cables, unexploded ordnance, and pollution, for example. This significantly complicates the early-stage planning and last minute risk assessment processes because professionals need to manually collect, assess, and integrate data about subsurface objects into a comprehensive risk assessment. To smoothen this process, ExcaSafeZone project, therefore, develops a system that collects location data, defines expert-based rules for safety risk assessment, and that synthesizes this into an open source prototype that visualized safety risks on a heat map.

To build a Safety Risk Heat Map system, the research team first gained knowledge about the safety hazards exwisting on the excavation site. To truly understand these risks, the research team conducted four workshops with excavator operators and work planners from the Dutch excavator operator school SOMA and professional association Het Zwarte Corps (HZC). In the first workshop, the researchers interviewed five respondents that have extensive experience in the various domains of excavation (e.g., waterworks construction, gas pipeline excavation, and road construction). They were asked to individually list sources of risk and to draw a situation that describes a hazardous situation that they remember from a project in the past. The three subsequent workshops presented various different scenarios to 12 professionals. For three different infrastructure configurations (streets, intersections, and areas without buildings or infrastructure), the professionals indicated how the presence of the abovementioned objects creates a risk to onsite safety and project continuity.

As a next step, the researchers analyzed the empirically derived risk scores. This not only allowed the team to better understand how practitioners perceive risks on the construction site, but also helped them to derive the first set of rules that relate the presence of an object onsite to risk. As a next step, the team further consulted what existing open data sources could be used to gain a rich set of information about the objects on the excavation site. Next, they analyzed the content, native format, granularity, and resolution of available data sources to better understand how the various data structures can be integrated into one information system. By using real data from the Hoogvliet district in the city of Rotterdam, the researchers finally developed and tested a prototype that integrates geo-referenced information from different open data sources on a heat map that displays safety risk levels.

The workshops revealed that practitioners judge about safety and project risks by using objects on various levels of granularity. Risk-related objects are, for example, cables and pipelines, older neighborhoods, fiber optic networks, trees, overhead railway power lines, ammunition and explosives, and polluted soil. Risk perception (scaled from 0 to 10 - highest risk) in relation to the identified objects varied between professionals. On average, for example, the 10 excavator operators rate the threats caused by the objects as high (scores ~ 7-8), while two job planners see much less risk (scores ~ 3-4). The average scores of the perceived risk for each object show that professionals agree mostly that explosives, soil, buried objects cause most risk (scores 9, 7 and 8 respectively). In addition, there was a consensus that archeological findings are the least risky with only 4 points.

The scores from the workshop were used to define three risk levels ranging from low risk (e.g. only one risk object with severity <5 points), medium risk (one risk with more than 5 points, or at least two risks with <5 points), and high risk (more than one associated risk with > 5points). We visualized these risks in our web-based heat map prototype. To identify the presence of the risk-related objects on the selected construction site cadaster data, topography data, cable and pipeline maps, ground pollution, land use maps, and road network data were collected, amongst others.

The final step to be taken in this project is the validation of the system with practitioners. The plan is to demonstrate the system to SOMA and members from HCZ and apply it during last minute risk analysis in a hypothetical project to see if the system enables the practitioners in their risk analysis and decision-making on site. Ultimately, the development of the Safety Risk Heat Map may help construction professionals to integrate risk data from open data sources on the fly, generate safety maps, and make informed go-no go decisions for performing excavation work on a particular site. The further development of the prototype for applications in real-life would require, as next steps, a development of user-friendly interfaces on portable devices, as well as the development of a more complete data set of infrastructure data.

University of Twente
dr. **Léon olde Scholtenhuis**,
dr. **Farid Vahdatikhaki**

Delft University of Technology
prof.dr. **Sisi Zlatanova**

Eindhoven University of Technology
prof.dr. **Jakob Beetz**,
dr. **Pieter Pauwels**

Gemeente Rotterdam – Kabels en Leidingenbureau

SOMA College Harderwijk

Beroepsvereniging Het Zwarte Corps

EXCELLENT BUILDING PERFORMANCE

The built environment is responsible for 40% of all resource depletion in Europe [1]. Reducing material and energy in buildings can thus lead to significant savings. The research presented here focuses on developing an optimisation method for building spatial designs that can handle objective functions from multiple disciplines like structural design or building physics.

Design Search Space

Optimisation problems are usually approached by defining a super structure of solutions; This research proposes to investigate a method in which no such structure is defined and a combination of the two methods [2].

A super structured approach has been developed in the form of a super cube representation, figure 1 on the left. Each cell in the cube holds—for each space—a binary value, the complete design is then formed by bit masks that each resemble a space. The algebraic nature of this representation can be exploited in state of the art optimisation algorithms (e.g. NSGA II), which find global optima with a high level of confidence but are time expensive in case of large design spaces.

A super structure free design search space has been developed in the form of a movable and sizable representation, figure 1 on the right. It facilitates an engineer to define modification rules that navigate a design search space without a super structure, for example by a simulation of co-evolutionary design processes, which is fast but gives no guarantee that a global optimum was found.

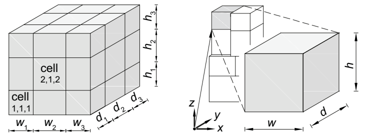


Figure 1 Left: Super cube. Right: Movable sizable.

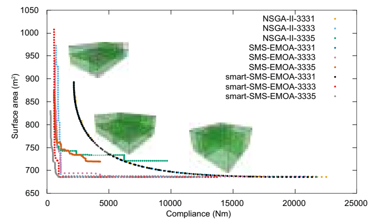


Figure 2 Optimisation results of a 3 _ 3 _ 3 super cube, optimising for 1, 3 and 5 spaces respectively [4]. Here smart mutation is proposed to generate constraint satisfying solutions without bias.

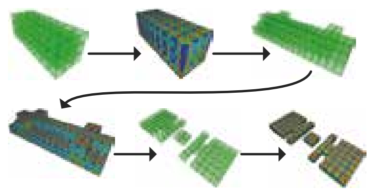


Figure 3 Simulation of a co-evolutionary design process [3].

Optimisation Toolbox

An optimisation toolbox has been developed to enable users to define their own optimisation methods using the presented representations. It currently contains a structural design (SD) package (FEM and topology optimisation), a building physics (BP) package (RC-network thermal heat simulation) and a visualisation package. Domain specific design information for a building spatial design (e.g. columns for SD or a window for BP) are generated by user defined design grammars. The toolbox has been benchmarked with simulations presented in [3], figure 3, and has successfully been used in optimisation with the NSGA II and SMS-EMOA algorithms [4], figure 2.

Outlook

Future efforts will focus on developing co-evolutionary design strategies for the free approach and smart mutation operators for the structured approach. Further a combination of both approaches will be developed to sequentially explore both design search spaces by using the free approach on optima of the structured approach and vice versa. Additionally, the methods will be assessed on their performance, be used to extract design rules and also be implemented in a real world Building Information Model (BIM) WoonConnect.

References

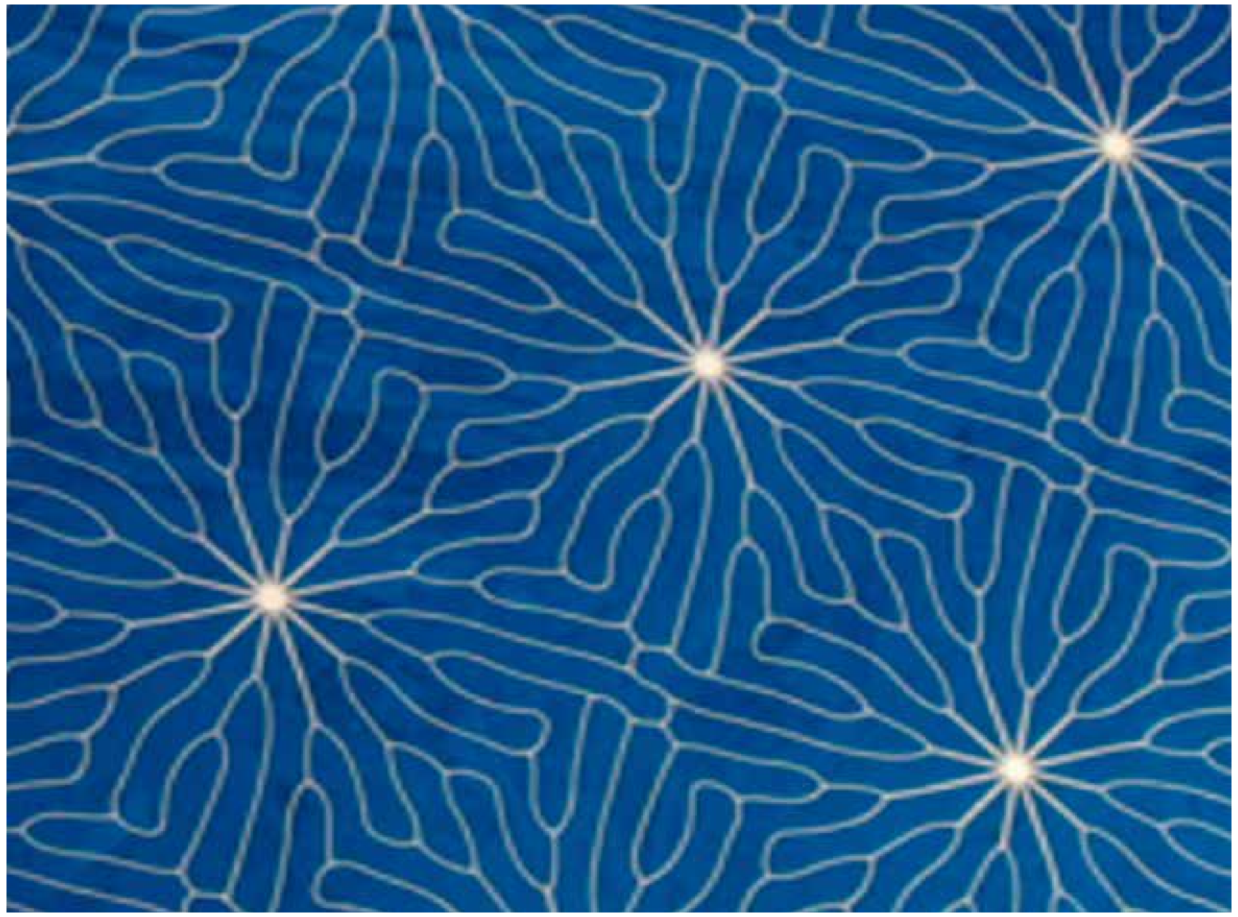
[1] European Construction Technology Platform (2005), Challenging and Changing Europe's Built Environment.
[2] Boonstra, S. et al. (2016), Super-structure and super-structure free design search space representations for a building spatial design in multi-disciplinary building optimisation, Electronic Proceedings of the 23rd EG-ICE workshop.
[3] Hofmeyer, H. & Davila Delgado, J. M. (2015), Coevolutionary and genetic algorithm based building spatial and structural design, Artificial Intelligence for Engineering Design, Analysis and Manufacturing, vol. 29, pp. 351-370.
[4] Van der Blom, K. et al. (2016), Multicriteria building spatial design with mixed integer evolutionary algorithms, Lecture Notes in Computer Science, No. 9921, pp. 453-462

Eindhoven University of Technology
ir. **Sjonnie Boonstra**,
dr.ir. **Hèrm Hofmeyer**,
prof.dr.ir. **Akke Suiker**,
prof.dr.ir **Bauke de Vries**

Leiden University
ir. **Koen van der Blom**,
dr.ir. **Michael Emmerich**,
prof.dr. **Thomas Back**

De Twee Snoeken

STW



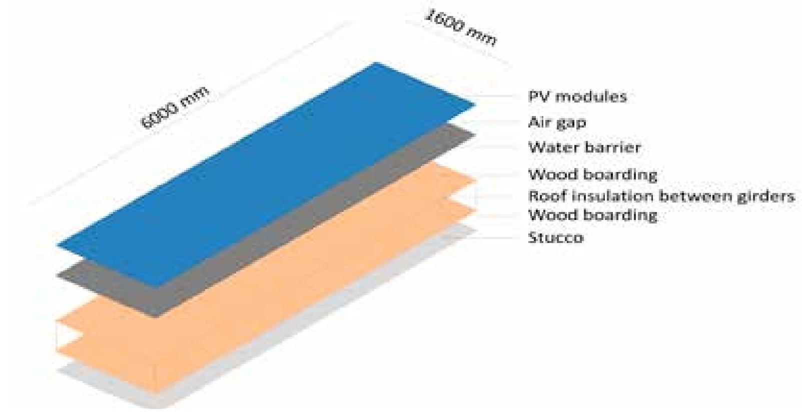
Applied solar cell in the BIPV field test

EXPLORATION OF BUILDING INTEGRATED PHOTOVOLTAICS

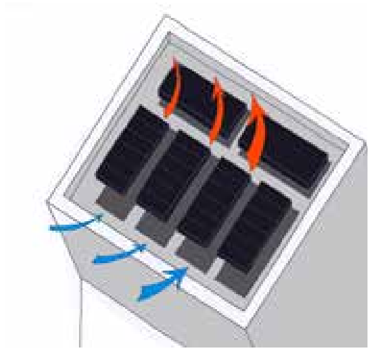
Within the EU, covering the whole life cycle of buildings, about 50% of extracted materials and 50% of all energy is consumed in the built environment. To lower collateral environmental impact, the EU has set a target to realize 27% energy efficiency improvement, 30% share of renewable energy, and 40% CO2 emission reduction by 2030. This has been translated in legislation that by the end of 2020, all new buildings have to be nearly Zero Energy Buildings (nZEB).

To realize a nZEB, two measures are typically applied, entailing a decrease of operational energy demand, mainly by adding building components such as insulation packages, and an increase of energy generation, mainly by adding or integrating energy generating devices. Consequently, material related environmental impact might create a collateral disproportionate burden, which is not well addressed in current assessment methods.

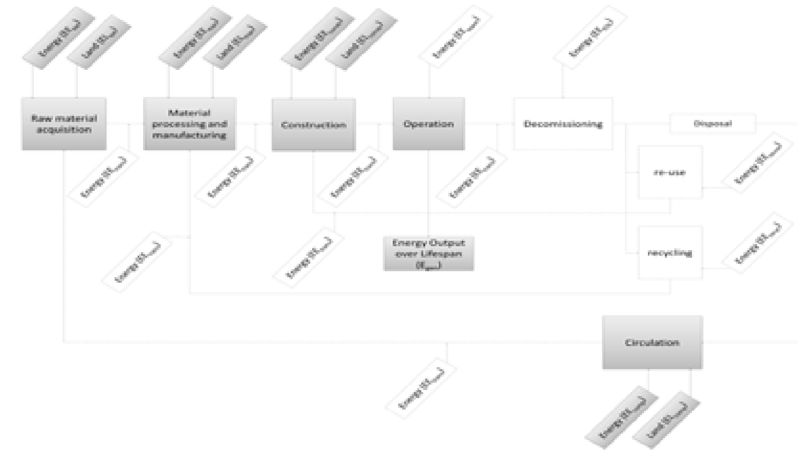
The aim of this research is to develop a framework for environmental impact assessment of Building Integrated Photovoltaic rooftop solutions, expressed in the claim on carrying capacity, based on theoretical data and collected data from a BIPV field test. The objective is to apply the framework to a BIPV field test and to develop an optimized BIPV rooftop element for this specific case based on assessment and possibly ranking of a generated set of alternatives.



BIPV rooftop field test roof element.



BIPV rooftop field test with indicative ventilation.



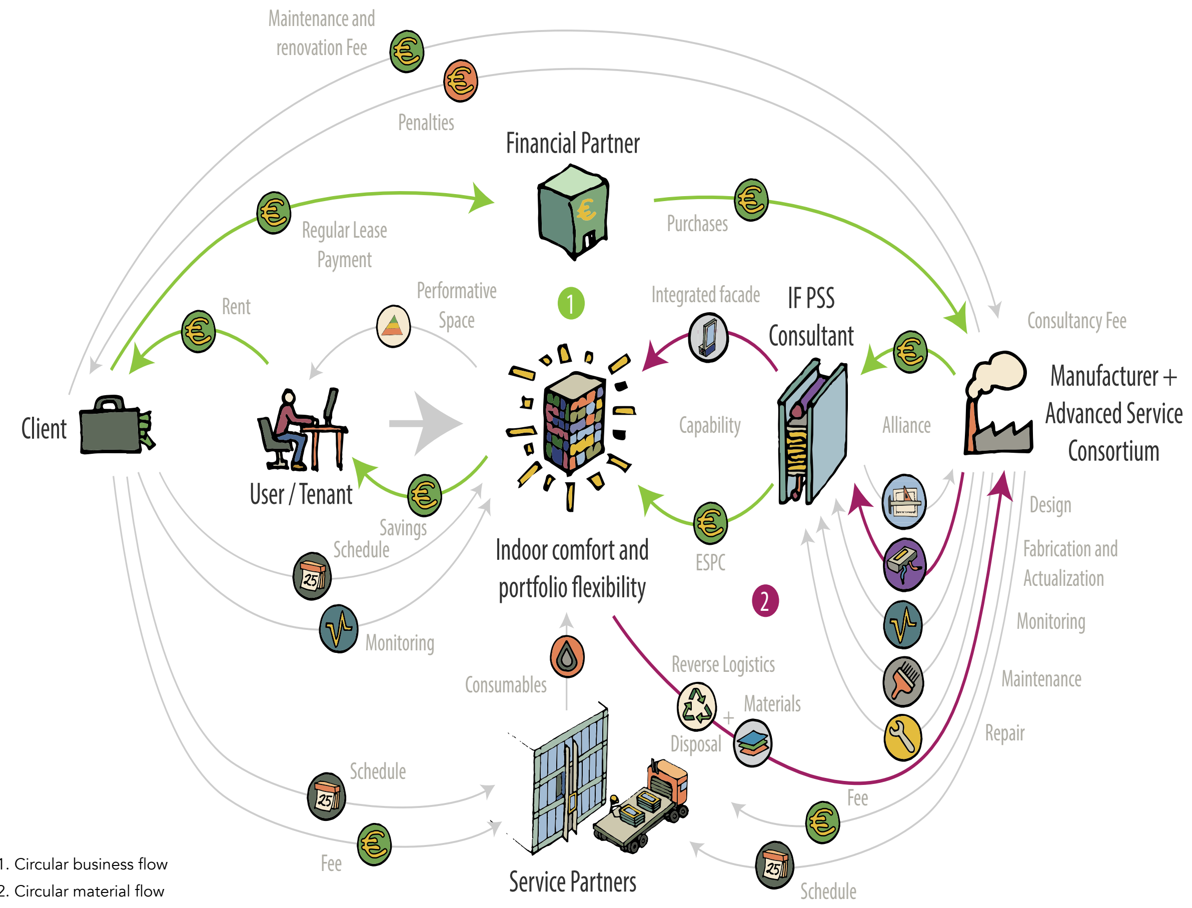
BIPV rooftop field test in The District of Tomorrow.

Eindhoven University of Technology
M.J. Ritzen

Zuyd University of Applied Sciences
R. Rovers, Z.A.E.P. Vroon

TNO
C.P.W. Geurts

NWO



1. Circular business flow
2. Circular material flow

FACADE LEASING

Façade Leasing explores a systemic transition in the construction industry, from a business structure based on the supply of products, to one based on the delivery of ongoing performance services. This could facilitate the introduction of circular economic strategies into the construction process.

Circular Economy

The principle of circular economic development is to preserve components and materials within closed loops of either biological or technical nutrients, maximizing the conserved value for any particular component. Parts should not simply be recycled, as this results in the loss of embodied energy and value, but instead reused or re-manufactured to extend their potential service lives.

Circular Business Model

A circular business model based on multifunctional façades as performance delivering tools could increase the rate and depth of building renovations, accelerate the market uptake of new building technologies, and optimize the reuse and recycling of components and materials within the construction industry. Innovation in building envelope and service technologies, and real estate development and management strategies, come together to turn this concept into a practical reality.

Delft University of Technology
ir. **Juan Azcarate-Aguerre**,
dr.ir. **Tillmann Klein**,
dr.ir. **Alexandra den Heijer**

ClimateKIC

AluEco I VMRG

Alcoa I Kawneer

Aldowa

Alkondor

DeHaan Westerhoff

Kindow

MHZ

Panelen Holland

Real Capital Systems

Renson

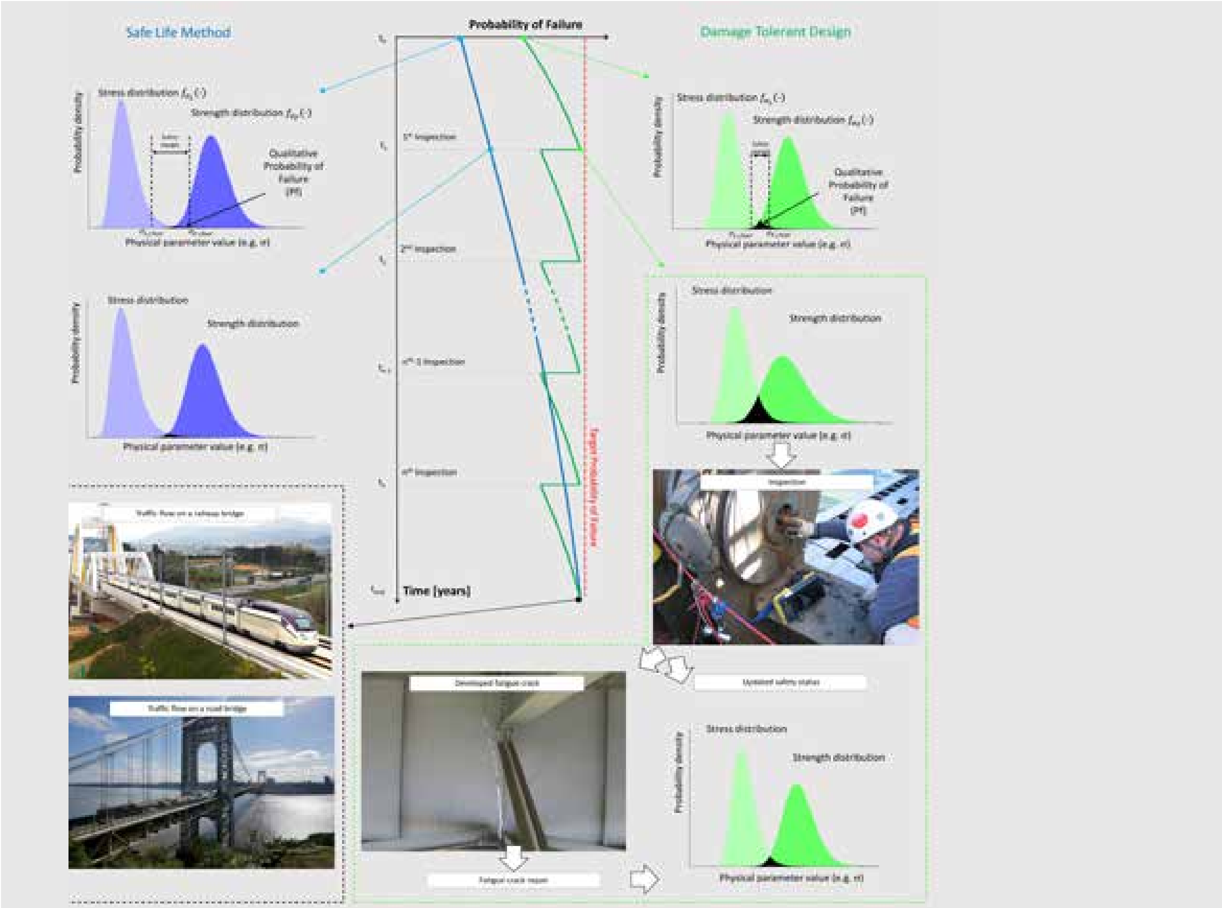
Scheuten

Schuurman Elektrokern Solutions

Somfy

Trox

VML Technologies



FATIGUE PARTIAL FACTORS FOR BRIDGES

Fatigue – crack initiation and growth due to repetitive loading – is one of the main failure modes of steel bridges. To ensure the bridge safety during its lifetime, partial factors should be used on both load effects and material resistance to keep the probability of failure less than its target value, set by considering failure consequences.

The current standards suggest two design methodologies. First, by using partial factors to prevent failure probability to reach its target value at the end of the life, which results in an expensive design. Second, using smaller partial factors and letting the failure probability get close to its target value but prevent failure by performing regular inspection and damage repair. While in the first method it is possible to use not large enough partial factors, in the second one, the lack of knowledge in (long) crack behaviour, critical crack length and inspection interval are the main issues.

The goal of this research is to solve these issues to assure fatigue safety in an economical way by making the best use of inspection techniques. Therefore, a sound physical and probabilistic approach will be followed considering the stochastic nature of involved parameters. Several possible inspection categories will be defined and for each one of them, an optimal partial factor will be set and required inspection interval and procedure will be regulated.

Eindhoven University of Technology
Bahman Hashemi MSc.,
Davide Leonetti MSc.,
prof.dr.ir. **Johan Maljaars,**
prof.ir. **Bert Snijder**

Rijkswaterstaat

ProRail

TNO

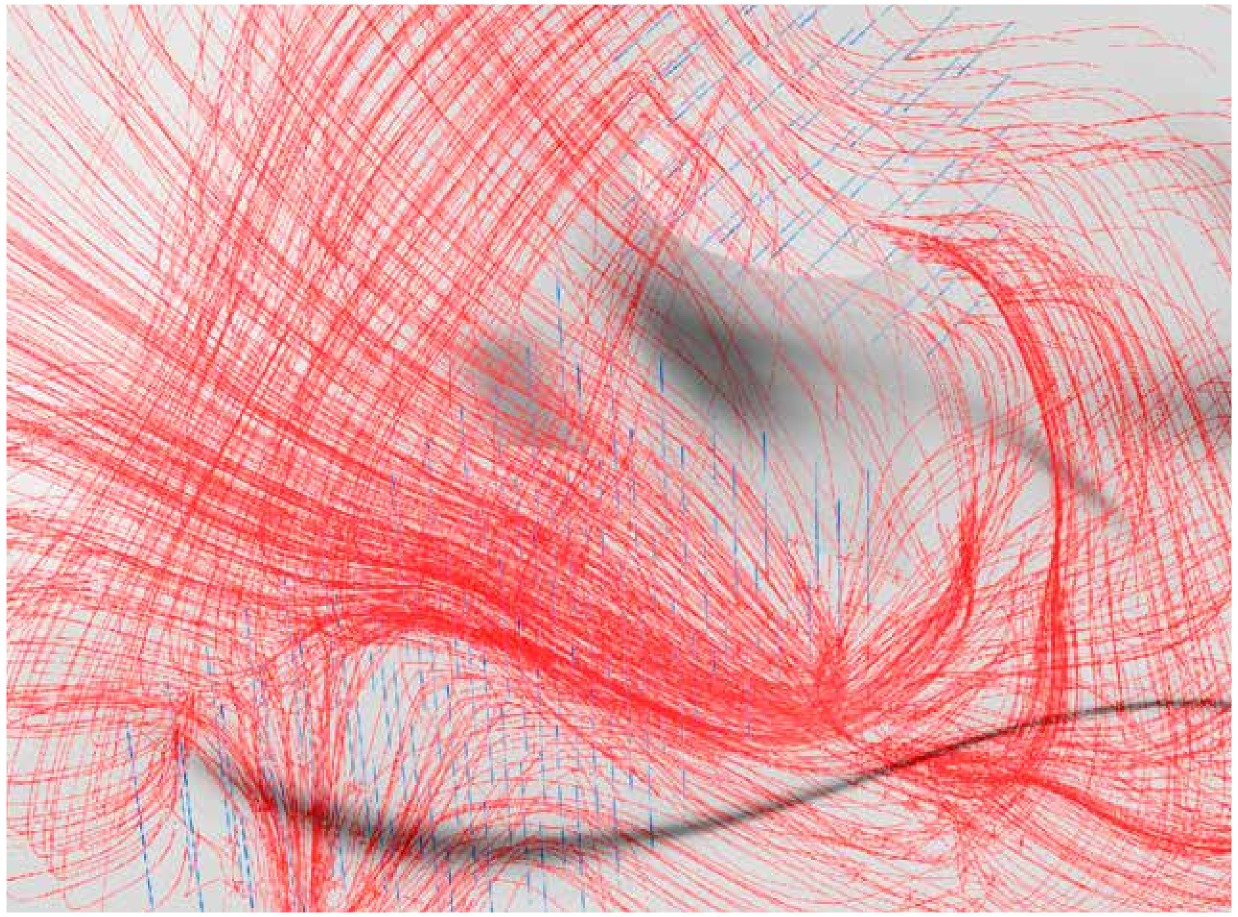
Fatigue is one of the main failure mechanisms and therefore an important design driver for bridge infrastructures. In Europe, the standard EN 1991-2 provides the fatigue load models for bridges and the European standard EN 1993-1-9 provides response models for fatigue. Together, these standards form the basis to check the fatigue life of the steel bridges.

Nowadays, the need to perform probabilistic analysis to verify the safety level of structures is continuously increasing. The safety level is considered in design by utilizing partial factors recommended by different standards. According to EN 1993-1-9, the partial factors depend on the assessment method and on the consequences of failure. The Safe-Life method is to be used for details where local formation of cracks could rapidly lead to failure, resulting in an unsafe character of relying on regular in-service inspection for fatigue damage. Damage Tolerant Design may be applied when in the event of fatigue damage a load redistribution between components can occur. This method is permitted to be used for inspectable details with a relatively low fatigue crack growth rate, a long critical crack length and / or multiple load paths.

It has been claimed by some previous studies that for Safe Life design, the current partial factors are too low. The Scandinavian countries, in their national annex, prescribe a partial factor that is up to 50% higher than the recommended values by Eurocode standard. By using higher values of partial factors, the design becomes more expensive and also the cost of upgrading the existing structures to meet new safety condition is considerable.

The aim of this research is to put forward a recommended set of partial factors for fatigue of steel bridges that is derived based on a probabilistic framework and by considering the required reliability level. The partial factors should be differentiated towards the inspection methods, the consequences of failure and the status of the structure. One of the goals for this research is to set the values for the required safety level (target reliability index) depending on the consequences of failure, for new and for existing bridges. Here, both human safety and economic considerations are important. Also, the possibilities of redistribution of forces, non-catastrophic failures and the warning effects influence the target safety value and must be considered in the study. In another step of this study, the scatter in fatigue resistance results will be determined and a model, which can predict the fatigue crack growth, will be defined. The evaluation method based on fracture mechanics is suited for an assessment of existing structures for which inspections are carried out. The model takes into account the influence of redistribution of forces and the behaviour of long cracks occurring in multiple load path bridges. Furthermore, measurement data are available for traffic loads. These data will be analysed and compared with the available fatigue load prediction models recommended by standards. The difference between measurement data and load models will results in a good understanding of the uncertainties related to the load models. In probabilistic fatigue assessment, these uncertainties related to the traffic load models, as well as the future trends envisioned in the traffic, and other uncertainties will be considered. An important aspect in the safety is the maintenance policy. Possible strategies will be explored – such as no inspections, general visual inspections and dedicated inspections for fatigue in certain types of detail. General descriptions, quantifications and checking methods will be developed to be applied into standards. Visual inspections are often applied to bridges. Despite the unreliability of this method, such inspections can be very valuable to detect cracks before entering the critical stage, and the benefit of these inspections needs to be quantified.

When all the previous aspects are quantified, the probabilistic assessment can be performed. A probabilistic framework will be built in which the aforementioned models, distributions and uncertainties are implemented. Inspections should be explicitly considered so that the influence of the inspection methods on the structural reliability can be determined and finally, the partial factors can be evaluated.



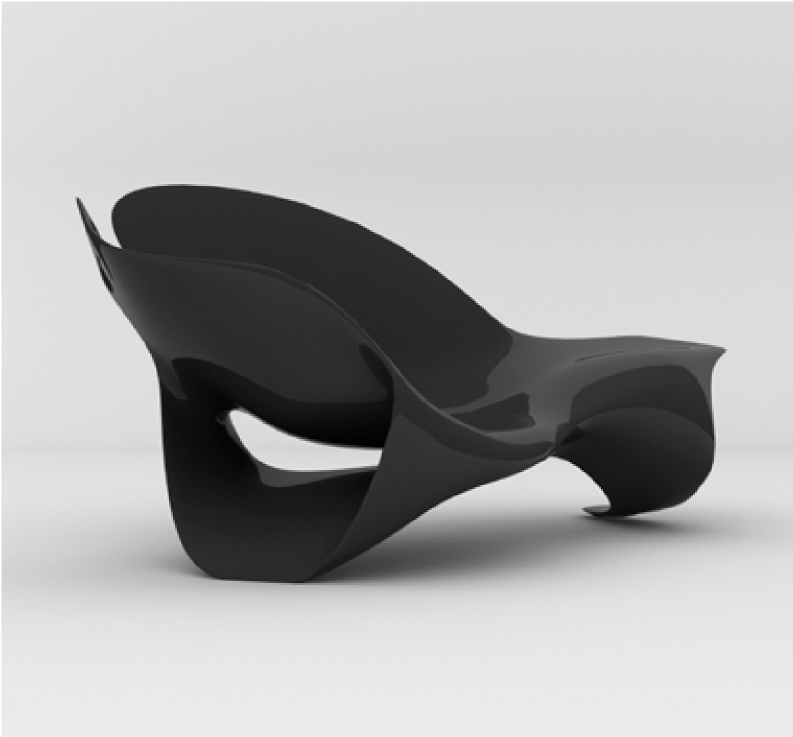
FIBROUS SMART MATERIALS

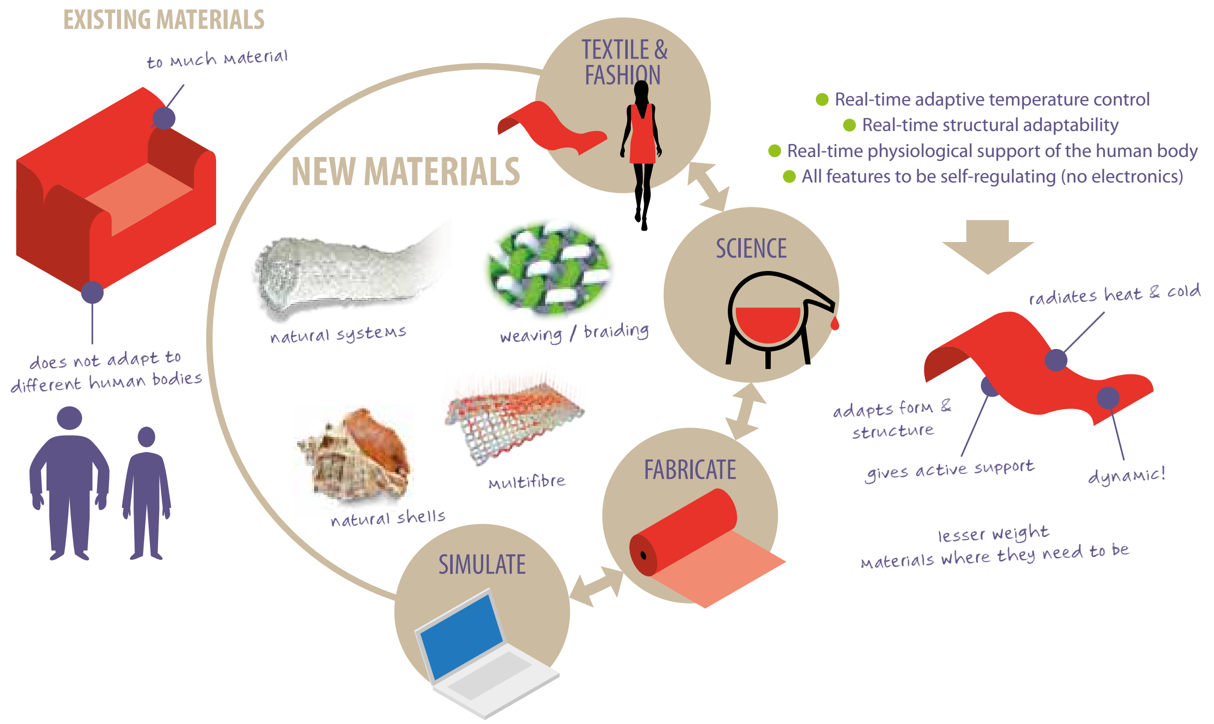
The project is an inter-disciplinary initiative for the 'designed engineering' of heterogeneous fibres with variable material behaviors to create real-time responsive interior environments (furniture systems). These smart furniture systems will embody properties of real-time adaptive temperature control, real-time structural adaptability and real-time physiological support of the human body. These properties shall be fully self-regulated (devoid of external power sources) via engineering multi-layered fibre compositions, which can sense the forces exerted by the human body and accordingly alter their physical properties. The scale of operation is chosen deliberately, considering the time-span of one year within which we will produce a fully operational 1:1 physical prototype and scientific material-research guidelines. A research through design approach with 3 iterations shall be adopted in this research: working on the yarn (U Twente + EURECAT), textile (TUE) and product (TUD). Each iteration will consist of the development of a prototype, the creation of future usage scenarios + business possibilities, and a workshop to envision future requirements. In this project, prototypes and material output will be co-designed with material scientists, architects, textile and industrial designers and will be used to assess 1) design challenges, 2) business opportunities, and 3) technical feasibility of scalable multi-performative interior systems for applications such as healthcare and future office environments.

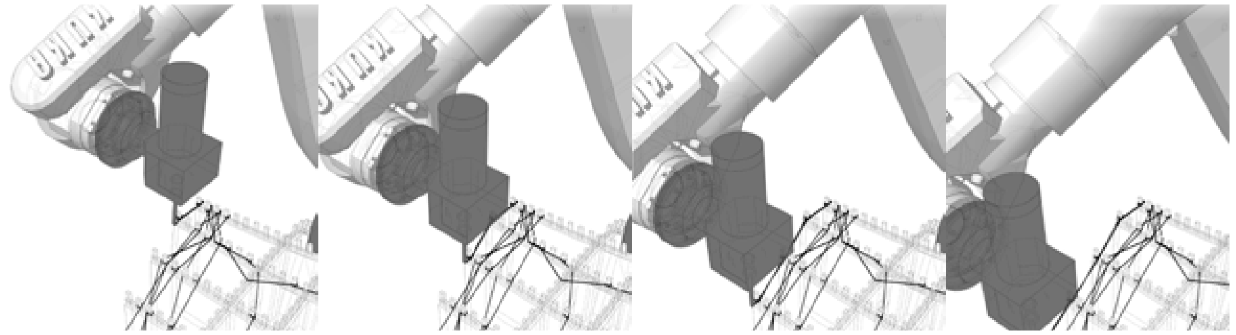
For the purpose of the research, a decision was made to choose the La Chaise Lounge designed by Charles & Ray Eames as an inspirational form. This voluminous lounge piece has a captivating elegance and allows a wide range of sitting and reclining positions. La Chaise has long since established itself as an icon of organic design. The selected chaise lounge geometry is tested as a boundary region while considering the active load of one person sitting on it. The topology of the fragment is later optimised based on supports and loads. In this process, the material from the parts that are less needed is removed till the initial supporting matter is defined. Following this step, according to the principal stress lines in different axes which indicate compression, tension and shear forces are extracted to be traced for creating the desired topology. The coordination of the point indices and the magnitude of moment and force vectors are calculated to identify the exact spots to manipulate the material distribution based on the defined cross section, material properties and directionality.

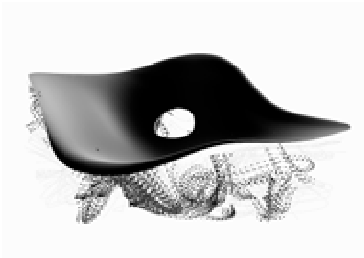
For understanding the composite structural behavior it was necessary to find an understanding of the relations between fibre arrangements and strength characterisation. The density and directionality of the fibres mainly specify the interaction between the fibres and determines different structural strengths. For this end, we conducted a robotic winding based cylinder experiment. The cylinder model was analysed as one union composite shell to observe the non-linear static stress flow over the model through finite element methods.

The resulting model indicated the stiffness distribution over the mesh varying between a range of 0.3 as minimum stiffness required to 1.0 as maximum stiffness required from one end to another. The stiffness factors are then interpreted into winding angle and the helix pitch which creates the new mesh topology corresponding to the directionality and density of fibres. The significance of the study is to predict how the fibers with certain configurations can interact and how composite strength values are affected by number of piles and directions. In this study, the winding angle value is the key parameter to gain a full control upon the local thickness and material deposition which feeds directly from stiffness factors.





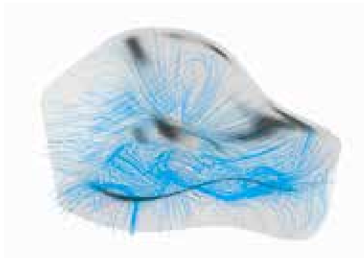


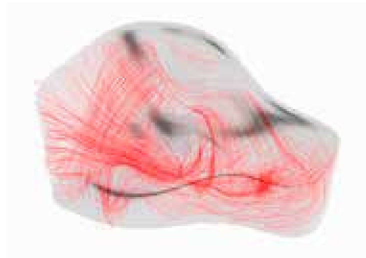


The structural strength statistics from the cylinder experiment are analysed and recorded. The experiment is followed by a prototype of a fragment from the concave area from the geometry. For winding technique it is important to consider measures to prevent fibres being offset in these areas. As a result, a waffle section containing grippers are designed to guide the fibres through the gripper teeth which allows the fibres to be positioned while they are under tension. The project is on-going and based on the robotic fabrication and material properties based feedback is now progressing into the next phase of 1:1 physical prototyping.

configurations can interact and how composite strength values are affected by number of piles and directions. In this study, the winding angle value is the key parameter to gain a full control upon the local thickness and material deposition which feeds directly from stiffness factors.

The structural strength statistics from the cylinder experiment are analysed and recorded. The experiment is followed by a prototype of a fragment from the concave area from the geometry. For winding technique, it is important to consider measures to prevent fibres being offset in these areas. As a result, a waffle section containing grippers are designed to guide the fibres through the gripper teeth which allows the fibres to be positioned while they are under tension. The project is on-going and based on the robotic fabrication and material properties based feedback is now progressing into the next phase of 1:1 physical prototyping.





Delft University of Technology
dr. **Nimish Biloria**, ir. **Javid Jooshesh**

Eindhoven University of Technology

University of Twente

EURECAT

Atelier Robotic

Reinforced geopolymer concrete bench made of the optimized geopolymer concrete mixture. The bench has been located in the street G.J. de Jonghweg, Rotterdam.

GEOCON BRIDGE

The sustainability of infrastructure projects is becoming increasingly important issue in engineering practice. This means that in the future the construction materials will be selected on the basis of the contribution they can make to reach sustainability requirements. Geopolymers are materials based on by-products from industries. By using geopolymer concrete technology it is possible to reduce our waste and to produce concrete in the environmental-friendly way. An 80% or greater reduction of greenhouse gases compared with Ordinary Portland Cement (OPC) can be achieved through geopolymer technology. However, there are limited practical applications and experience. For a broad and large scale industrial application of geopolymer concrete, challenges still exist in the technological and engineering aspects.

The main goal of GeoCon Bridge project was to develop a geopolymer concrete mixture and to upscale it to structural application. The outputs of projects provide input for development of recommendations for structural design of geopolymer based reinforced concrete elements. Through a combination of laboratory experiments on material and structural elements, structural design and finite element simulations, and based on previous experience with OPC concrete, knowledge generated in this project provides an important step towards a "cement free" construction.
The project was performed jointly by three team members: Microlab and Group of Concrete Structures from Technical University of Delft and Technical University of Eindhoven.

Fig.1 Slump test of optimized concrete mixture.

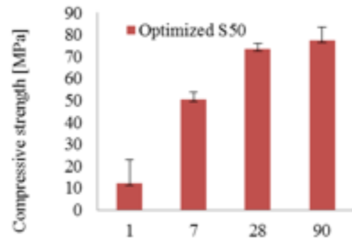


Fig.2 Compressive strength test results for reference and optimized mixture.

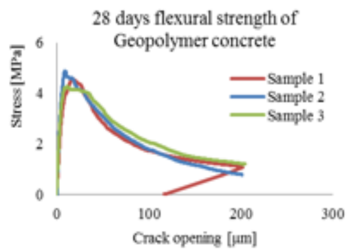


Fig. 3 Flexural strength at 28 days.

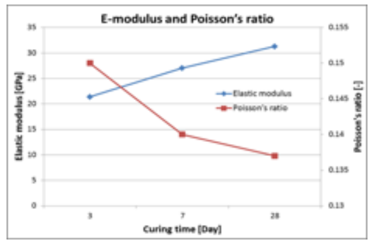


Fig.4 E-modulus and Poisson's ratio.

Optimization of Geopolymer Concrete Mixture

The main aim of this task is optimization of the geopolymer mixtures for structural application. This was performed by characterization of workability, mechanical (compressive strength, flexural strength, elastic modulus, etc.) and shrinkage properties of geopolymer paste, mortar and concrete. Several mixtures developed in the Microlab have been initially considered for optimization of the setting time, workability and mechanical properties. The optimized mixture is shown in Table 1. The workability, compressive strength, flexural strength and elastic modulus of the optimized concrete are measured after 7, 28 and 90 days of wet curing and are shown in Fig. 1 - Fig. 4.

The properties of the optimized mixture are used for upscaling to geopolymer reinforced concrete element and as input for the structural design of the geopolymer bridge.

Upscaling and Structural Application

The current design codes for concrete structures are based on compressive strength (concrete class) and most of the other mechanical properties that are used in calculations (e.g. E-modulus, tensile strength, flexural strength, etc.) are based on known relations between these properties and the compressive strength. Therefore, the first step was to investigate if the relations, valid for conventional concrete, are also valid for the geopolymer concrete. Furthermore, the long term development of mechanical properties over time, as well as structural behaviour of the reinforced elements over time had to be known. The flexural behaviour (flexural capacity, crack width and crack spacing) of reinforced geopolymer beams for optimized mixtures were examined (Figure 5). Generally, for similar compressive strength, flexural and splitting strength of geopolymer concrete are similar to the flexural and splitting strength of conventional concrete. However, the E-modulus of geopolymer concrete is around 20% lower than of the conventional concrete and this should be considered in the structural design of geopolymer concrete. Based on long term mechanical tests it was found that probably curing conditions that are commonly used for concrete (wet curing until the age of 28 days) might not be appropriate for geopolymer concrete.

Results on reinforced geopolymer beams showed that the structural performance of geopolymer concrete (flexural capacity, crack spacing and crack width) is quite similar to OPC concrete control beam (that had similar E-modulus, but lower compressive strength) (Figure 6). The results of the four-point bending tests shows that the stiffness of reinforced geopolymer concrete is lower than the stiffness of OPC concrete, and confirm that the overall stiffness of reinforced AAC is decreasing over time, as the beam tested at an age of 69 days show a lower stiffness than the beam tested at an age of 33 days. Possibly due to this reduced stiffness, reinforced AAC beams show larger deflections and exhibits more ductile behavior (higher rotational capacity) compared to reinforced OPC concrete, which is consistent with results reported by (Shah & Shah, 2017).

Components:		Optimized geopolymer concrete mixture S50
Fly ash		200
Blast furnace slag		200
Aggregate [0-4 mm]	789.14	
Aggregate [4-8 mm]	439.81	
Aggregate [8-16 mm]	524.69	
Alkaline activator		212
(BaCl2.2H2O) admixture		2 (0.5 wt.% of the binder)

Table 1 Optimized concrete mixture design [kg/m3].

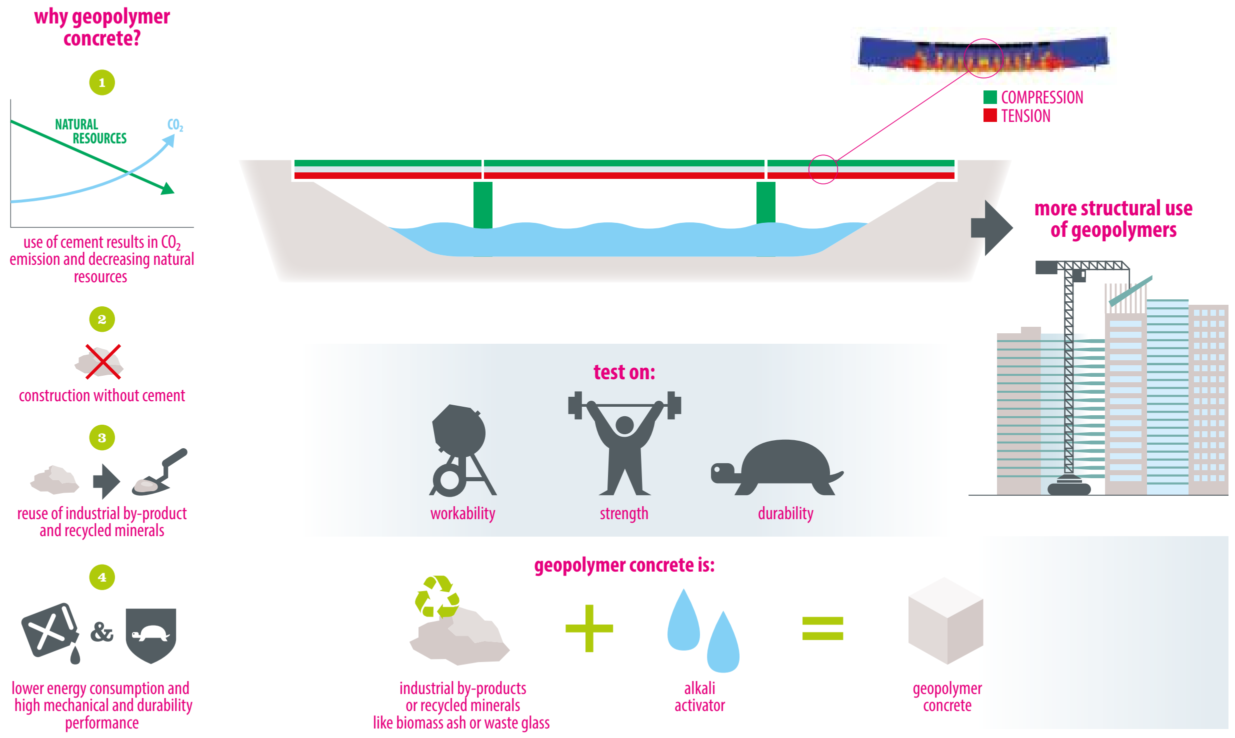


Fig 5 Test set-up. Top: painted side of beam for image analysis. Bottom: LVDTs to measure deformation.

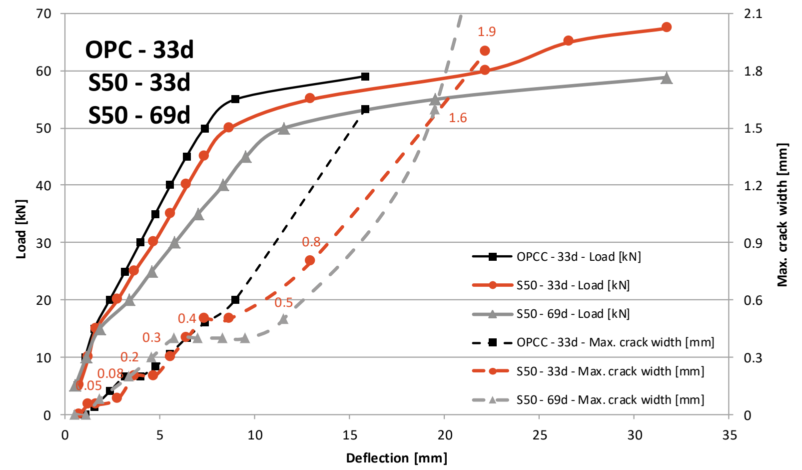


Fig 6. Development of cracks during four-point bending tests on S50 beams at 33 and 69 days and comparison with OPC concrete control beam, results by Zhekang Huang. S50 specimens have been cured (20°C and 95% RH) for 28 days. After this, the samples were exposed to laboratory conditions (20°C and 55% RH) until testing. OPC concrete was kept in the mould for 33 days (covered with plastic) in lab conditions and then unmoulded.

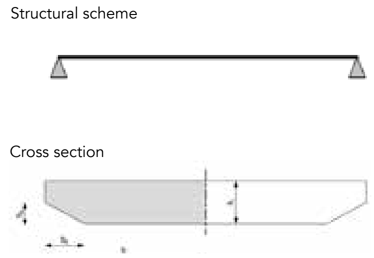


Fig. 7 Geopolymer concrete bridge

Delft University of Technology
dr. **Guang Ye**, dr.ir. **Mladena Luković**, **Bahman Ghiassi**, **Zainab Aldin** MSc., **Silke Prinsse** MSc, **Jonh Liu**, **Marija Nedeljković** MSc, prof.dr.ir. **Dick Hordijk**, ir. **Paul Lagendijk**, **Albert Bosman**, **Ton Blom**, **Maiko van Leeuwen**, **Zhekang Huang**, **Ulric Celada**, **Chengcheng Du**, **John van den Berg**, **Arjan Thijssen**

Eindhoven University of Technology
prof.ir. **Simon Wijte**

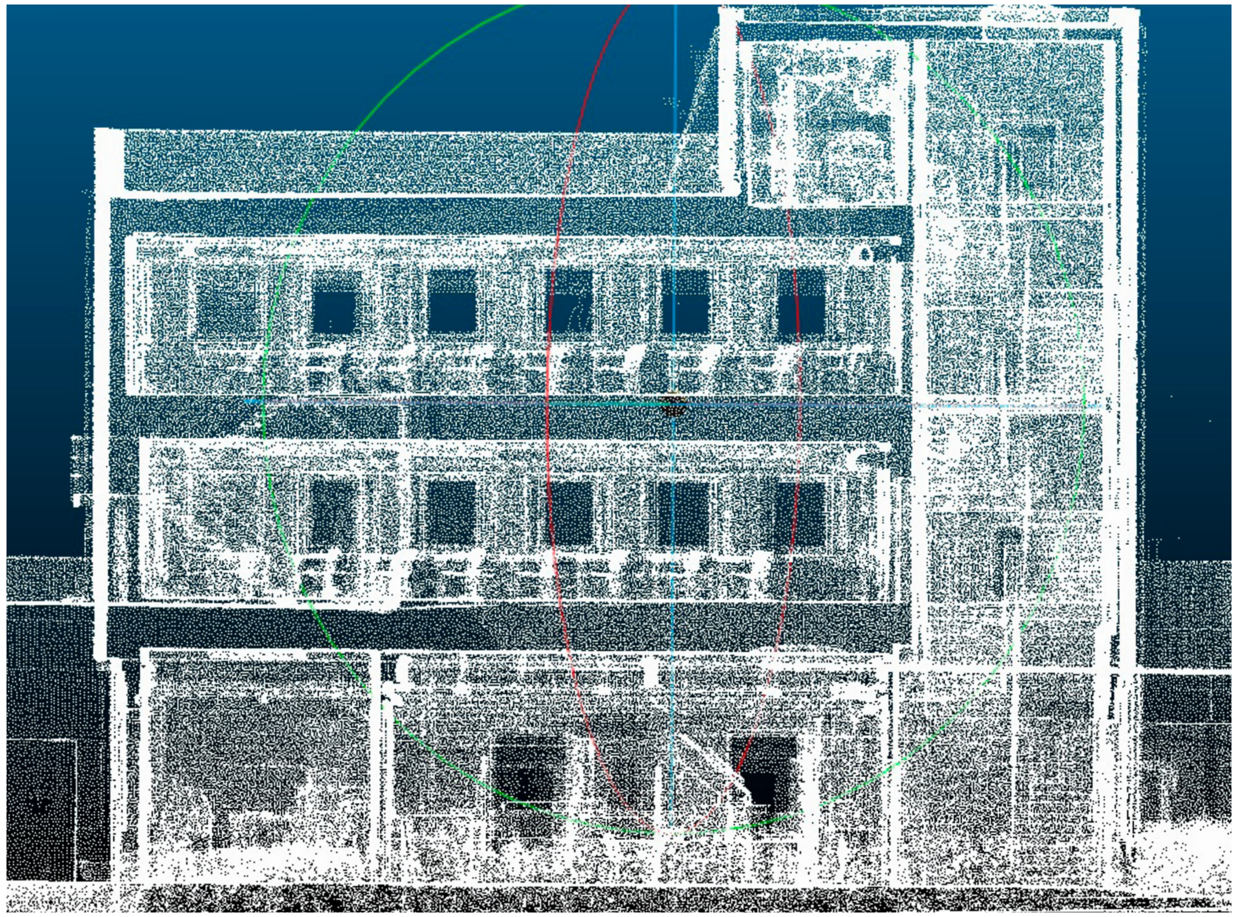
However, care should be taken with the large deflections that might be governing with the design of reinforced concrete (and geopolymer) bridge. Therefore, focusing on a prestressed geopolymer bridge, where benefits of fast hardening can also be utilised, might be more promising than design and execution of a reinforced geopolymer bridge. Then, beside the investigated mechanical properties, creep and shrinkage of the geopolymer mix become very important and have to be investigated in future.

Design of Geopolymer Concrete Bridge

A reinforced geopolymer concrete bridge was designed. The calculation has been made for a bridge with a span of 12 m and a width of 3 m The total height is chosen equal to 350 mm (see figure 7). The mechanical properties of geopolymer concrete were taken from the optimized mixture. The required amount of reinforcement were calculated and it seems practical. The deformations value of 58 mm due to the permanent load without creep effects being considered seems rather large. Recalculation should be done when the shrinkage and creep tests are completed.

Main Output of the Project

1. The work performed in Microlab was done within the additional master thesis project of Zainab Aldin. The optimized mixture was also applied in the design and production of reinforced geopolymer concrete bench. The bench has been placed in the street G.J. de Jonghweg, Rotterdam and news in https://www.rotterdam.nl/nieuws/groene-betonbank/
2. The work performed in the group of Concrete Structures was done within the MSc thesis project of Silke Prinsse.



GEOMETRIC INFORMATION GENERATOR

Renovation of existing buildings is known as an essential stage in reduction of the energy losses. A critical part of this process is simulation of energy usage based on geometric reconstruction of the building. Following many research projects focused on parameterizing the energy usage, various energy modeling methods were developed during the last decade. However qualified simulations highly depend on external geometric information of the building.

On the other hand, by development of the accurate 3D measurement tools such as laser scanners, the industry is highly eager to use this technology for innovative solution. Architectures, engineers and constructors were the early users of laser scanner products. But the application of this technology still does not meet the increasing industrial demands. The automation of 3D information extraction from laser point cloud and object detection tasks are still significant challenges of industry.

The aim of this project is designing a platform through which required geometric information can be efficiently generated to support energy simulation software. Developing a reliable procedure which extracts required information from measured data and delivers them to a standard energy modeling system is the main purpose of the project. Reaching to this point is highly beneficial both in short and long term. Energy labels for existing buildings are an urgent demand of authorities.

Having a functional application to speed up energy simulation and energy label generation would be an early achievement of this project. In addition, methodological development of such a system would have a significant contribution in the as-built modeling research field

Expected Outcomes

Current renovation procedure for energy efficiency is too slow and expensive and is not covering market demand. One of the bottlenecks is having a reliable 3D as-built model to run the energy simulation. However, 3D modeling is a wide field in science with various methods and standards. Energy simulation software, such as Energy plus, requires general geometric information from indoor area of buildings. The coordination of heating zones, dimension and orientation of walls, position and shape of the openings, position and volume of energy sources are quite essential information for a reliable energy simulation. Therefore, the expected outcome is an efficient platform which provides such information.

Optimization between automation and accuracy for efficient energy simulation is the main target of this platform. Nowadays laser scanners are frequently used to provide dense as-built measurements. However, the cost of modeling is often more than the measurement. Following algorithm describes an easy-to-use procedure which leads to creation of input file enriched by the geometric information for Energy Plus software. This procedure is designed to tackle the complexity of dealing with laser data, reducing uncertainty in calculations and avoiding unnecessary details.

The Platform and the Functional Sections

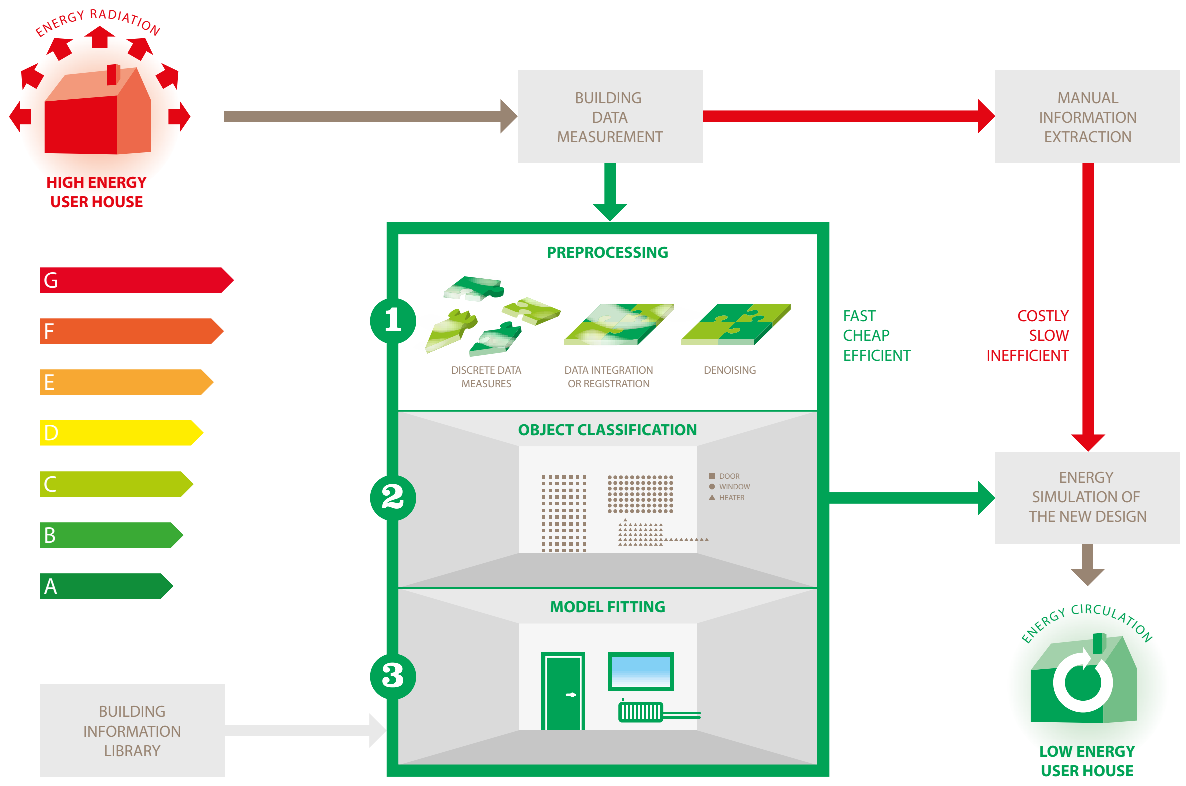
The user can operate the platform through an interface (Figure 1). Push buttons, selection from the list and simple mouse clicks are all user efforts to interact with the program. Users can track the procedure through some illustrations and apply required changes. Functional sections are illustrated in Figure 2 and are explained in following subsections.

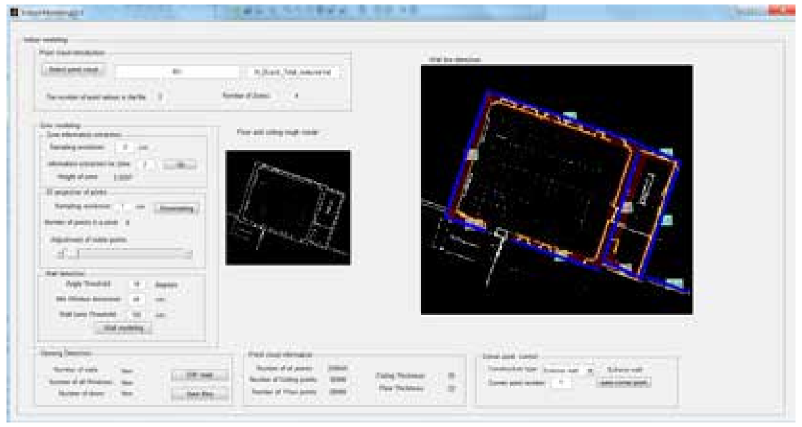
File Input and Floor Detection

The Point cloud of a building can be uploaded as a text file to the system. At the beginning the point cloud does not have any structure. In this part histogram matching analysis is used to divide the point cloud to several levels. For this aim, Z value of all points are used to generate a histogram. Some knowledge based conditions is employed to automate the process. For instance, in the histogram, a minimum between two maximums (the ceiling points from previous story and the floor points from the next story) is considered as a clue to draw a division line. Or a condition of at least 3m distance between division lines is also considered to avoid wrong detections. Then the points of different stories are labeled.

Segmentation of Level Points

A typical story is composed of a floor, a ceiling and some walls. In the most cases the floor and the ceiling are horizontal objects and the walls and their attached objects (doors and windows) are vertical. In this section, an algorithm is used to differentiate the floor and ceiling points from the rest of the points. The user can select a story to recall corresponding points. Ceiling points and floor points of the selected story are detected and labeled through a plane fitting function.





Wall Extraction

The aim of this section is recognition of wall models. This is an essential step because the orientation of walls and their dimensions are very important information for energy simulation. Instead of the common methods which is based on plane detection in 3D space, 3D points are projected on XY plane as a main source of wall detection. This strategy brought some computational advantages. After some successive computations (mentioned in the flowchart of figure 2), main walls and their attributes are estimated.

Openings Extraction

Detection of empty spaces on the wall is the main clue of automatic window detection. The idea is that laser points are denser and uniform on wall area. While glass windows are appeared as holes in point cloud. As another clue, windows with curtain or closed doors are appeared as a slight intrusion or extrusion in the dominant wall plane.

Verification and Labeling

Extracted information needs to be controlled and verified by the user. For this reason, a user-friendly section is designed. The results of automatic object detection are represented to the user through the interface. The user is enabled to apply some corrections with simple efforts such as mouse clicks and selection from a list. This information finally is combined with automatic driven information.

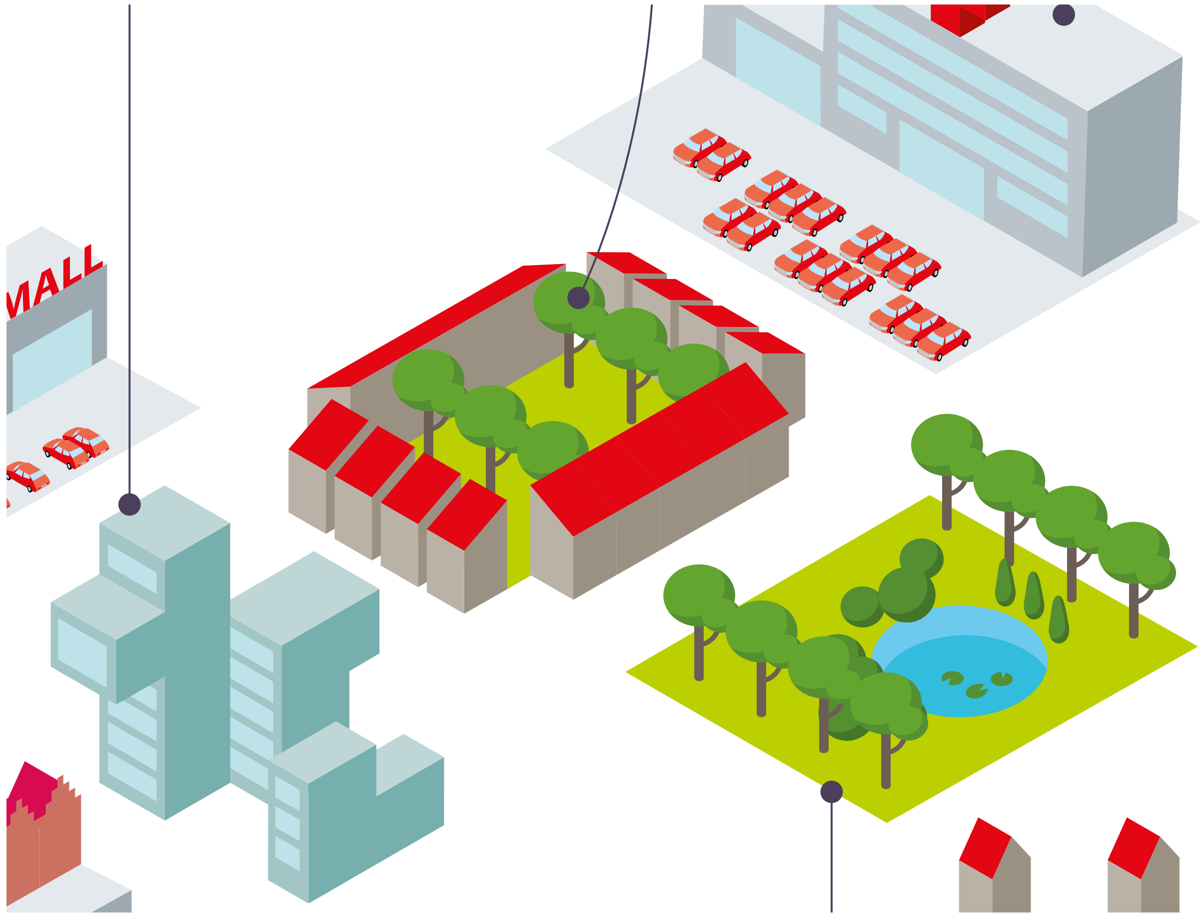
Save in Energy Plus Format

Verified information should be transformed to a format which is readable for Energy plus. A sample .txt file is used for this aim. Geometric information is added to the end of this file and saved in a separate name.

University of Twente – VISICO
Meisam Yousefzadeh MSc.

3DGeosolutions Co.

GlobId



HAPPY SENIOR LIVING

In developed countries, the share of the elderly (65+) is growing quickly. In the Netherlands it might reach 25 to 30% of the population by 2040 (see Figure 1). We design best living concepts for the elderly, based on a research in their residential preferences. Our novel methodology combines insights from social sciences and architecture. A stated choice experiment retrieves the willingness-to-pay of the elderly for a set of relevant attributes of the dwelling, building and location. The attributes with the highest valuation are used as an input for a flexible architectural design.

Research in Consumer Preferences

We performed a stated choice experiment among 460 participants of a Dutch national on-line panel in the age group 65-74. Each respondent was offered twelve randomly composed choice sets, consisting of two alternative dwellings each. The dwellings were specified as apartments sized between 70 m2 and 110 m2, situated in a building with a lift and specifically designed for elderly needs. The alternative dwellings were created from the reference dwelling by adjusting its attributes to a higher or lower level. The reference dwelling was specified as follows:

- apartment, elderly-accessible, equipped with amenities including: a lift in the building, an elevated toilet, broad doorways, etc.
- living space 90 m2
- balcony 12 m2
- open kitchen
- medium size building with 20 to 80 dwellings
- public garden next to the building
- common meeting space for the residents of the building
- entrance through an indoor small atrium
- outdoor parking, residents only
- located in a smaller city on a distance from a larger city
- price around 225.000 euro

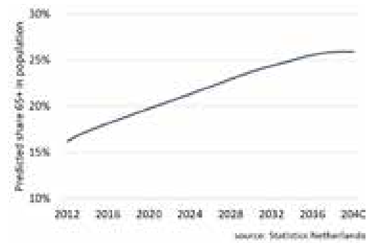
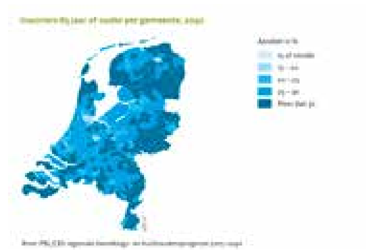


Figure 1 Predicted share of 65+ in Dutch population will likely reach 25% in 2040. Source: Statistics Netherlands, PBL regional population forecast.



Consumer Toolbox and the Best Living Concepts

The stated choice experiment allows to calculate the value elderly attach to the specified attributes of the dwelling, building and block. We translated these results into an easy to interpret consumer toolbox, see Figure 2. The toolbox contains the mentioned attributes; the levels of the attributes are ordered by the values they have for the elderly.

The toolbox works as follow. The reference dwelling is indicated in yellow. Alternative attribute levels that increase or decrease the utility of the resident compared to the reference, are colored in the toolbox green respectively red.

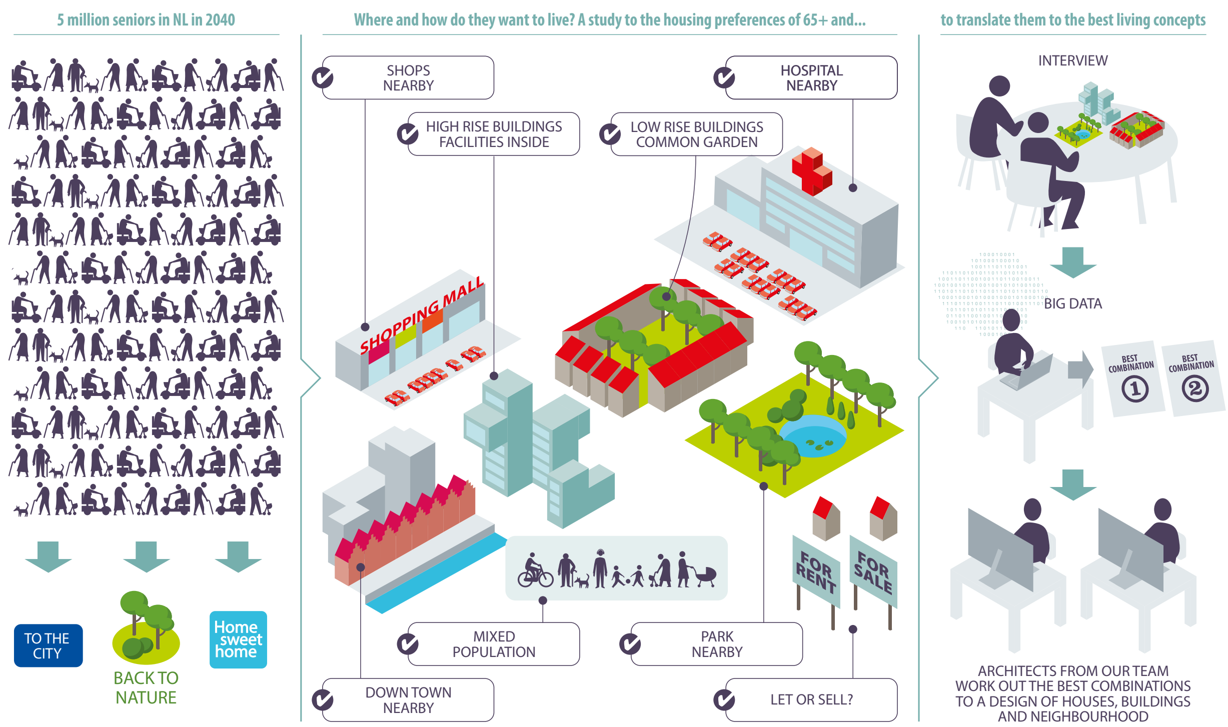
The consumer toolbox offers clear trade-offs between improving and worsening the levels of certain attributes. Thus it allows to construct a variety of best living concepts that meet various financial, geographical and other restrictions. Consider, for instance, a situation in which a larger dwelling of 110 m2 located in a small building with only 20 other dwellings is desirable. This yields a higher utility to the residents than the reference dwelling. However, increasing the dwelling size and reducing the number of apartments in a building lead to higher construction costs per dwelling, as compared to the reference, which may be undesirable. Our toolbox offers a possibility to limit the cost increase by reducing the levels of other attributes. One example is designing an entrance through an outdoor gallery instead of an atrium. The resulting dwelling will meet the requirements concerning the size and generate a higher utility than the reference dwelling, while keeping the cost increase limited.

The toolbox shows that safety, comfort and the right combination of social cohesion and privacy play a very important role for the elderly. A large enough apartment and a private outside space of a reasonable size are valued high, as well as a common garden and a common space in the building (possibility of social contacts). The necessity to park on-street (a higher chance of a car robbery, necessity to cruise for parking) and a large building (lower cohesion, a higher chance that if something happens to you, this will go unnoticed) have a negative effect.

Architectural Design

In order to make the consumer toolbox practically applicable for designers and architects, we transformed it into an architectural toolbox. The architectural toolbox had to meet the requirement of flexibility, i.e. contain architectural elements that allow to compose different combinations from the consumer toolbox. Furthermore, we paid attention to enabling a social and communal way of living without compromising on privacy, and to ensuring accessibility and comfort for the elderly.

Figure 3 contains an illustration of the elements of the architectural toolbox. Panels (a)-(b) illustrate two possible block compositions: a semi-urban setting and an urban setting. Grouping several buildings together in a block allows to share a common garden and a number of communal spaces and services. Different buildings are connected to each other through a walking passage; they all can be reached from inside each building without walking outside.



	Size dwelling	Balcony /garden	Openness dwelling	Size building	Parking	Entrance	Common garden	Common space	Location
higher living comfort/ utility	110 m2	Ground floor, garden 12m2	Open kitchen, no doorway living-sleeping	< 20 dwellings	Indoor parking garage	Large hall/atrium with lift	Yes, private, residents only	Yes, a small cafetaria or a supermarket	Suburbs of a larger city
reference dwelling	90 m2	No ground floor, balkony 12m2	Closed kitchen, no doorway living-sleeping	20-80 dwellings	Outdoor parking reserved for residents	Small hall with a lift	Yes, public garden	Yes, a recreation area/ a meeting place	Small city, more than 15 min driving to larger city
lower living comfort/ utility	70 m2	No ground floor, balkony 5m2	Open kitchen, doorway living-sleeping	> 80 dwellings	Public parking on the street	Outdoor gallery	NO	NO	Larger city

Figure 2. Consumer toolbox: best living concepts.

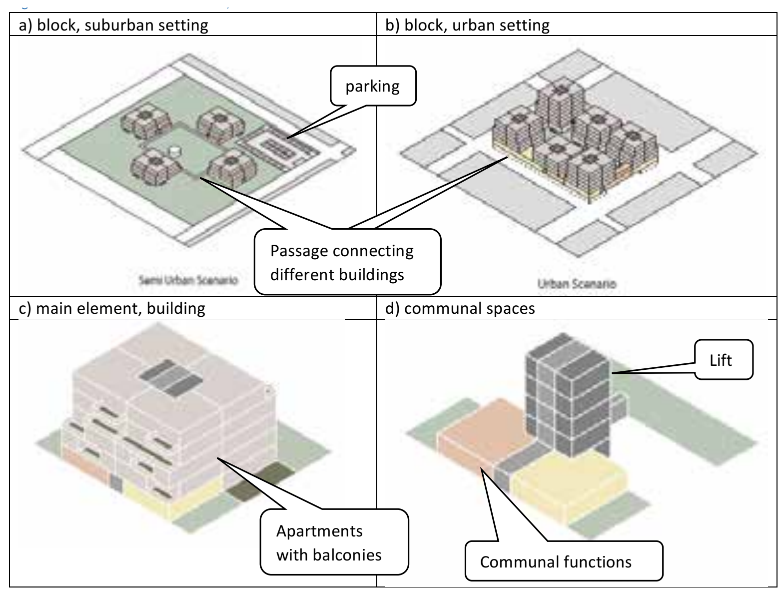


Figure 3 Architectural toolbox, extract .

Parking can be realized on the ground level, respectively in a corner of the block or in the middle of the block. In the former solution, the parking place offers a direct entrance to the passage connecting different buildings. The latter solution makes more space available for other construction, but sacrifices the communal garden in the middle of the block. An underground parking is a third possibility.

Panels (c) and (d) zoom in at the building, which consists of four dwellings per floor, central core circulation with lift and stairs. The entrance leads to a large atrium from where the stairs and the lift can be reached. The building allows different combinations of the attribute levels from the consumer toolbox. The size of the four dwellings can be easily adjusted between 90m2, 110m2 and 70m2. The number of floors can vary to adapt to different needs and urban settings. Dwellings on higher floors are equipped with balconies, dwellings on the ground floor with a small garden. Communal functions located on the ground floor include an atrium, a lift, and other spaces such as residents-only meeting rooms and a restaurant, a small supermarket or a shop.

Conclusion

This study applied a novel approach to designing best living concepts for a specific target group: senior homeowners. The consumer toolbox and the architectural toolbox we have developed, can be used to realise different concepts of senior housing that fit various practical restrictions and requirements. Financial limitations as well as specific characteristics of a location may make it impossible to always realise the first-best living concept. The consumer toolbox yields insights into what attributes can be sacrificed with the smallest loss in the value of a dwelling for the seniors. The architectural toolbox offers construction elements that allow to adjust the design to a specific situation.

Eindhoven University of Technology
dr. **Ioulia Ossokina**,
prof.dr. **Theo Arentze**

Delft University of Technology
prof.ir. **Dick van Gameren**,
dr.ir. **Dirk van den Heuvel**

We thank **Arjen Deetman** and **Giorgio Larcher** for excellent research assistance.

HEALTHY LEARNING ENVIRONMENT

The quality of school buildings in the Netherlands is in general not so good, with a very large percentage of them not complying with good practices for the indoor environment. According to RVO (Rijksdienst voor Ondernemend), in about 70% to 80% of the total of Primary and Secondary schools, CO_2 concentration levels are much too high. This can cause an increase in health-related issues, which in turn affects the performance from both pupils and teachers. In addition to this problem, schools across the territory also have high energy costs, which represent up to 20% of their fixed costs. Oftentimes, School Boards are faced with important decisions to make regarding the improvement of the quality of the indoor environment in their facilities; it is not a simple and straightforward task, as there are many factors that need to be taken in consideration, such as costs and energy use in the buildings. And of course, all schools do not have the exact same priorities, nor do they face the exact same issues regarding their indoor environment. Therefore, a balance between all the elements mentioned above –i.e. Indoor Environment Quality, energy use and costs- will not be the same for every school. How to achieve this balance and support the schools in their decision making is at the core of this project.

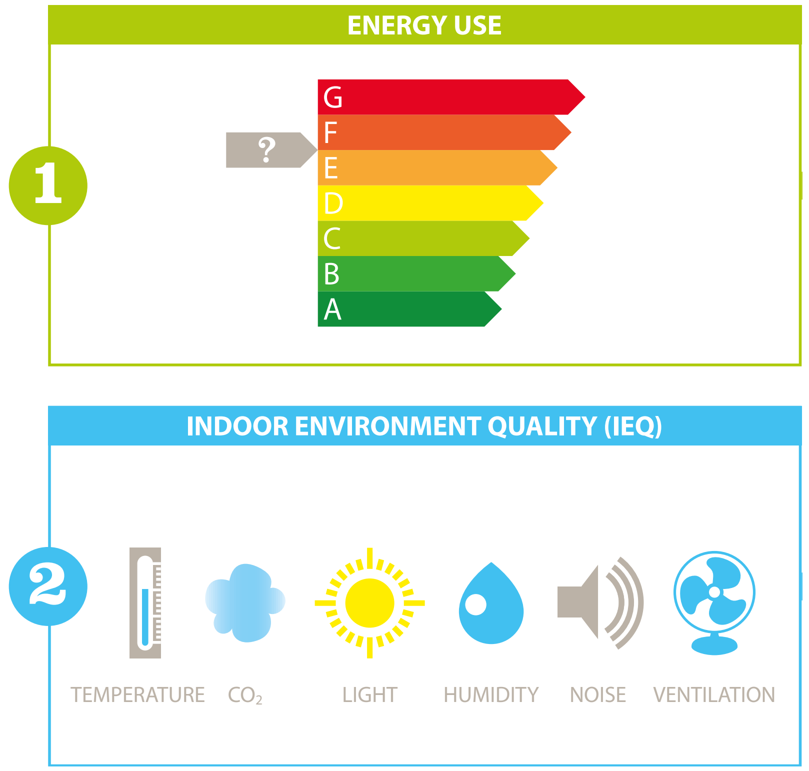
The goal of the project 'Developing a model for the balance of energy use and Indoor Environment Quality in school buildings' is to create a decision support model to help School Boards make informed decisions about actions that they could implement in their facilities to improve the quality of the indoor environment and to reduce their energy consumption. To achieve this goal, a model was designed using three data flows as input: First, data for the following Indoor Environment Quality parameters: CO_2 concentration, indoor temperature, relative humidity, daylight factor and acoustics; Second, data for energy consumption; and third, data about the perceived satisfaction of the users, which was collected by means of questionnaires. By means of two separate Co-Creation sessions, the structure of the model was defined and further refined. The model is divided in four quadrants: Assessment of the current situation, definition of the priorities, selection of recommended actions and display of improvement. An explanation of each of the quadrants is given below.

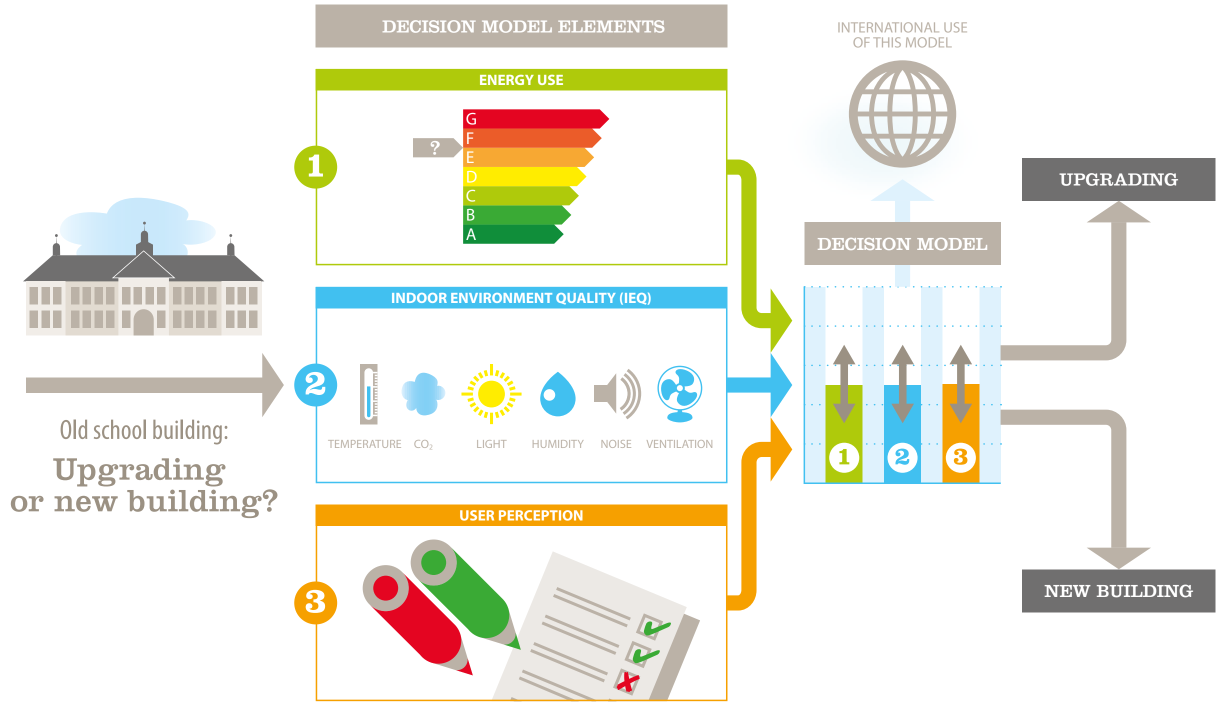
Assessment of the Current Situation

The initial step is to understand the current situation of the school building. In this step, the measurements of Indoor Environment Quality parameters and energy use, together with the results of questionnaires are collected. Next, each individual parameter (CO_2 concentration, temperature, relative humidity, lighting and acoustics) is benchmarked to the values of the reference scenario and a 'grade' is given. Currently, the values used in the reference scenario are the ones given in the 'Frisse Scholen' Program of Demands, Class B. It is worth mentioning that the reference scenario is not the most optimal one -although it gives an acceptable basis for this project-, and for this reason a proper benchmark -discussed with and approved by the School Board- would be developed during the implementation of the model.

Definition of the Priorities

The recommended actions that will be presented to the schools are evaluated according to four focus areas: energy savings, indoor environment quality, user satisfaction and costs. However, not all schools have the same priorities or desires; or they might not be fully aware of what their actual priorities or desires are. For this reason, a questionnaire is designed to help School Boards determine the ranking in importance of these four areas.





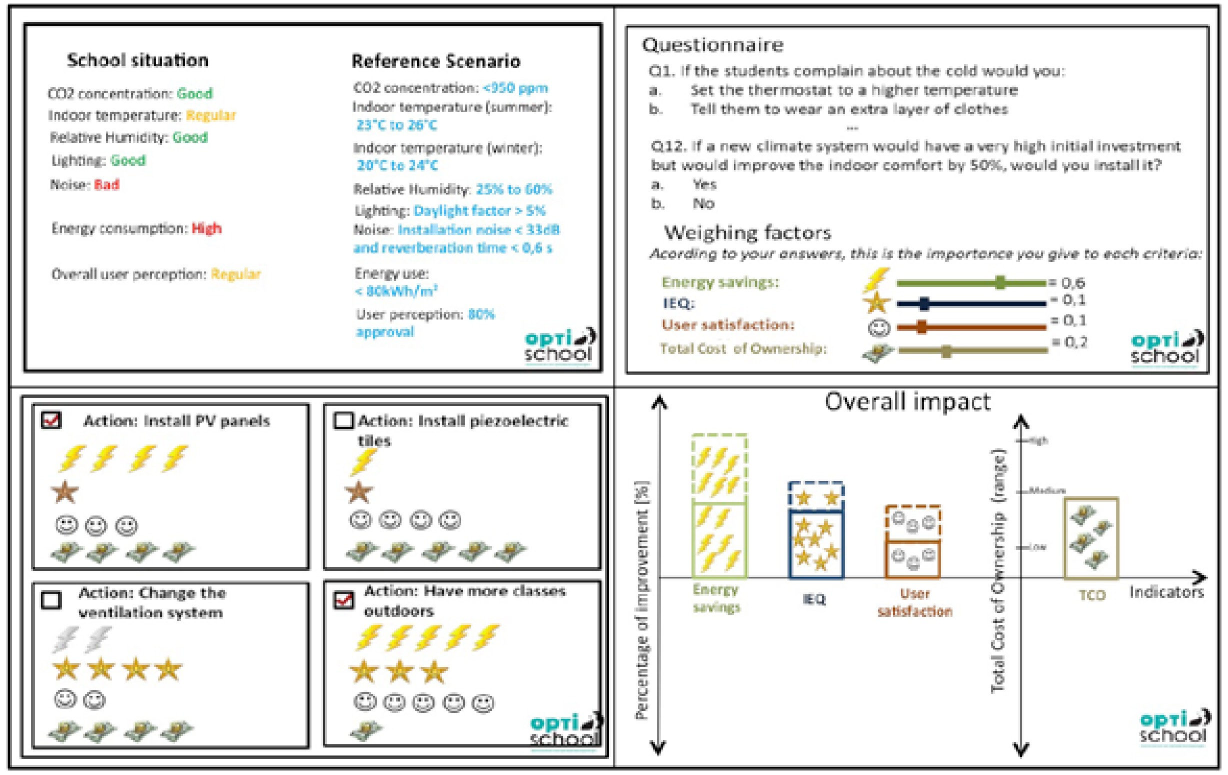


Figure 1 Representation of the Interface of the Model

Eindhoven University of Technology
Stephanie Villegas Martinez MSc.,
dr.ir. **Marcel Loomans**

Stichting OPTI-School
dr. **Ad den Otter**,
Ferdie van de Winkel

Eco Klima BV
Noor Schellens

Selection of Recommended Actions

Once the focus areas are ranked according to the desires of the School Board, the Analytic Hierarchy Process is followed to determine which actions are suitable. Applying this process, information is categorized in a hierarchy of both alternatives (actions) and criteria. Subsequently, the information is summarized to determine a relative ranking of the applicable solutions.

Display of Improvement

The total contribution of the actions to the improvement of each of the focus areas is shown. A bars diagram is used to indicate how much improvement there is after applying the actions. Figure 1 shows a representation of how the interface of the model could look like.There are thousands of prospective schools that could benefit from the use of this model and the recommendations it gives. At the moment, there is not a specific tool in the market that can take into account the preferences of the main stakeholders, and propose solutions accordingly. This is one of the strongest points of this solution, and the one that could make it an attractive and well-received tool among the schools. The solutions offered by the tool are based on real-time measurements of the performance of the buildings, and as such, they would tackle the main issues at hand. Furthermore, the solutions (actions) included are backed by the expert knowledge of professionals in the field who were consulted during the development of the model; in this manner, it is possible to assure to the schools that the information given by the tool, is of the highest quality.

IMPENETRABLE INFILTRATION

Het is wenselijk dat gebouwen beschikken over voldoende en de juiste mogelijkheden om te ventileren. Buiten de benodigde ventilatievoorzieningen is het echter de bedoeling een gebouw zo luchtdicht mogelijk te maken ten einde comfortklachten en onnodig energiegebruik te voorkomen. In het Bouwbesluit zijn eisen met betrekking tot de luchtdoorlatendheid – het tegenovergestelde van luchtdichtheid – opgenomen. Met betrekking tot een heel gebouw wordt in Art. 5.4 lid 1 het volgende geëist: De volgens NEN 2686 bepaalde luchtvolumestroom van het totaal aan verblijfsgebieden, toiletruimten en badruimten van een gebruiksfunctie is niet groter dan 0,2 m³/s. De Universiteit Twente en de Technische Universiteit Eindhoven hebben samen met het bouwbedrijf SelektHuis gewerkt aan de uitvoering van het onderzoek "Impenetrable Infiltration". Dit onderzoek naar de luchtdoorlatendheid van woningen kent drie onderdelen, namelijk:

A. Een veldonderzoek waarbij luchtdichtheidsmetingen worden uitgevoerd op vrijstaande woningen om zo te bepalen tegen welke keuzemogelijkheden luchtdichtheidsmeters en uitvoerende bouwondernemingen aanlopen om de luchtvolumestroom te beïnvloeden;
B. Een deskstudie waarbij rapportages van luchtdichtheidsmetingen worden bestudeerd om zo te bepalen wat de huidige stand van zaken is betreffende de luchtdichtheid van woningen;
C. Een vergelijkend praktijkonderzoek naar het bepalen van de luchtdichtheid, waarbij drie partijen de luchtdichtheid van dezelfde duurzaam gebouwde vrijstaande woning zullen vaststellen.

Om de veldstudie en het praktijkonderzoek uit te kunnen voeren, is de nodige apparatuur aangeschaft. Er is gebruik gemaakt van een blower door, een ventilator en een digitale manometer. Tevens is er tijdens de metingen gebruik gemaakt van twee dataloggers om de luchtdruk, binnen- en buitentemperatuur elke minuut vast te leggen. Er werd een anemometer gebruikt om de windsnelheid op locatie te bepalen. Om inzicht te krijgen waar eventuele lekken zich bevonden, werden een rookmachine en een infraroodcamera ingezet. De veldstudie heeft betrekking op negen verschillende cases, welke in 2014 zijn opgeleverd. De omvang van de thermische schil en het netto vloeroppervlak van deze woningen zijn vastgesteld aan de hand van de EPC-berekening.

Voor het bepalen van de luchtvolumestroom is, in lijn met EN 13829, het gemiddelde van twee meetseries genomen; één op onderdruk en één op overdruk. Het drukverschil over de gevel liep hierbij op van 20 tot 90 Pa. Elke meetserie bestond uit het bepalen van een baseline met tien meetwaarden vooraf, twaalf debietmetingen en tot slot een baseline met wederom tien meetwaarden achteraf. Vervolgens is met deze meetwaarden teruggerekend naar een luchtvolumestroom bij een drukverschil van 10 Pa. In totaal zijn er zestien metingen uitgevoerd op de negen cases. De gemeten luchtvolumestroom (qv;10 in dm3/s) is gedeeld door het netto vloeroppervlak (in m2) van de woning om zo tot de karakteristieke luchtvolumestroom (qv;10;kar in dm3/(s·m2)) van de woning te komen, welke kan worden vergeleken met de bij de vergunningaanvraag gespecificeerde ambitie in de EPC-berekening. Bij vier cases is er een tussentijdse meting en een eindmeting uitgevoerd.

Het Bouwbesluit eist een luchtdoorlatendheid die kleiner is dan 200 dm3/s en een EPC van maximaal 0,6. Een dergelijk lage EPC wordt bij deze woningen bereikt door onder andere een qv10;spec te behalen van 0,625 dm3/s per m2 vloeroppervlak. Van de negen bemeten cases in de veldstudie, voldeden alle woningen aan het Bouwbesluit. Alleen Case 2 en 5 voldeden niet aan de ambitie, zoals aangeven in de EPC-berekening. Van de negen cases voldeed één woning, Case 5, vlak voor oplevering nog niet aan de in de EPC-berekening gestelde ambitie van 0,625 dm3/s per m2 vloeroppervlak.

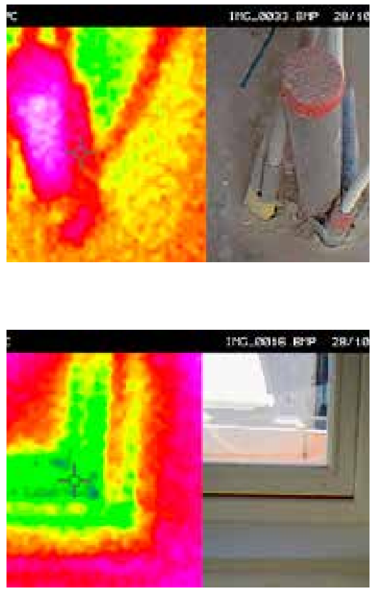
Case 2 naderde op het moment van meten nog niet de oplevering, maar de stap om van 1,10 naar 0,625 dm3/(s·m2) te komen, is nog wel vrij groot. De aansluiting van het dak op de muurplaat verdient in de meeste woningen nog enige aanvullende aandacht.

#	Case nummer en locatie	Datum meting	Netto-volume (m3)	Nettovloer-oppervlak (m2)	Gemeten lucht-volumestroom $q_{v;10}$ (dm³/s)	Karakteristieke luchtvolumestroom $q_{v;10;kar}$ (dm³/(s·m²))
1	1. Radio Kootwijk	06-10-2014	682	2656	290,28	1,09
2		08-12-2014			95,83	0,36
3	2. Doorn	28-10-2014	451	171	194,58	1,14
4		28-10-2014			188,75	1,1
5	3. Rijssen	28-10-2014	391	156	134,03	0,86
6		17-12-2014			94,58	0,61
7	4. 's-Graveland	12-11-2014	339	135	95,97	0,71
8		08-12-2014			56,81	0,42
9	5. Soest	12-11-2014	482	191	430,56	2,26
10		12-11-2014			234,31	1,23
11		08-12-2014			150,56	0,79
12	6. Bruinisse	01-12-2014	509	196	115	0,59
13	7. Teteringen	01-12-2014	*622	*217	133,06	0,61
14		01-12-2014			129,17	0,6
15	8. Waddinxveen	18-12-2014	550	215	113,19	0,53
16	9. Brielle	18-12-2014	646	260	158,47	0,61

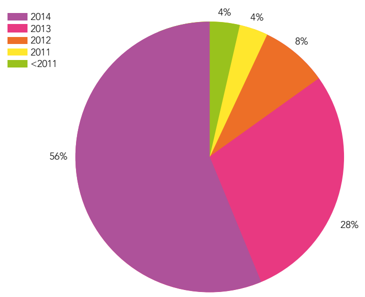
Resultaten van luchtdoorlatendheidsmetingen in het veldonderzoek

Case	Datum meting	$q_{v;10}$ (dm³/s)	Oordeel Bouwbesluit	$q_{v;10;kar}$ (dm³/(s·m²))	Oordeel ambitie EPC-berekening
1	08-12-2014	95,83	Voldoet	0,36	Voldoet
2	28-10-2014	188,75	Voldoet	1,1	Voldoet niet
3	17-12-2014	94,58	Voldoet	0,61	Voldoet
4	08-12-2014	56,81	Voldoet	0,42	Voldoet
5	08-12-2014	150,56	Voldoet	0,79	Voldoet niet
6	01-12-2014	115	Voldoet	0,59	Voldoet
7	01-12-2014	129,17	Voldoet	0,6	Voldoet
8	18-12-2014	113,19	Voldoet	0,53	Voldoet
9	18-12-2014	158,47	Voldoet	0,61	Voldoet

Beoordeling resultaten van luchtdoorlatendheidsmetingen



Warmte opnames case study woningen



Verdeling woningen naar bouwjaar in de rapporten voor de deskstudie

University of Twente
dr.ir. **Bram Entrop**

Eindhoven University of Technology
prof.dr.ir. **Jan Hensen**,
dr.ir. **Marcel Loomans**

Nieuwenhuis Groep
ing. **Ron Brons**

Selekthuis Bouwgroep
ing. **Alex Veldhoff**, ing. **Jan Averink**

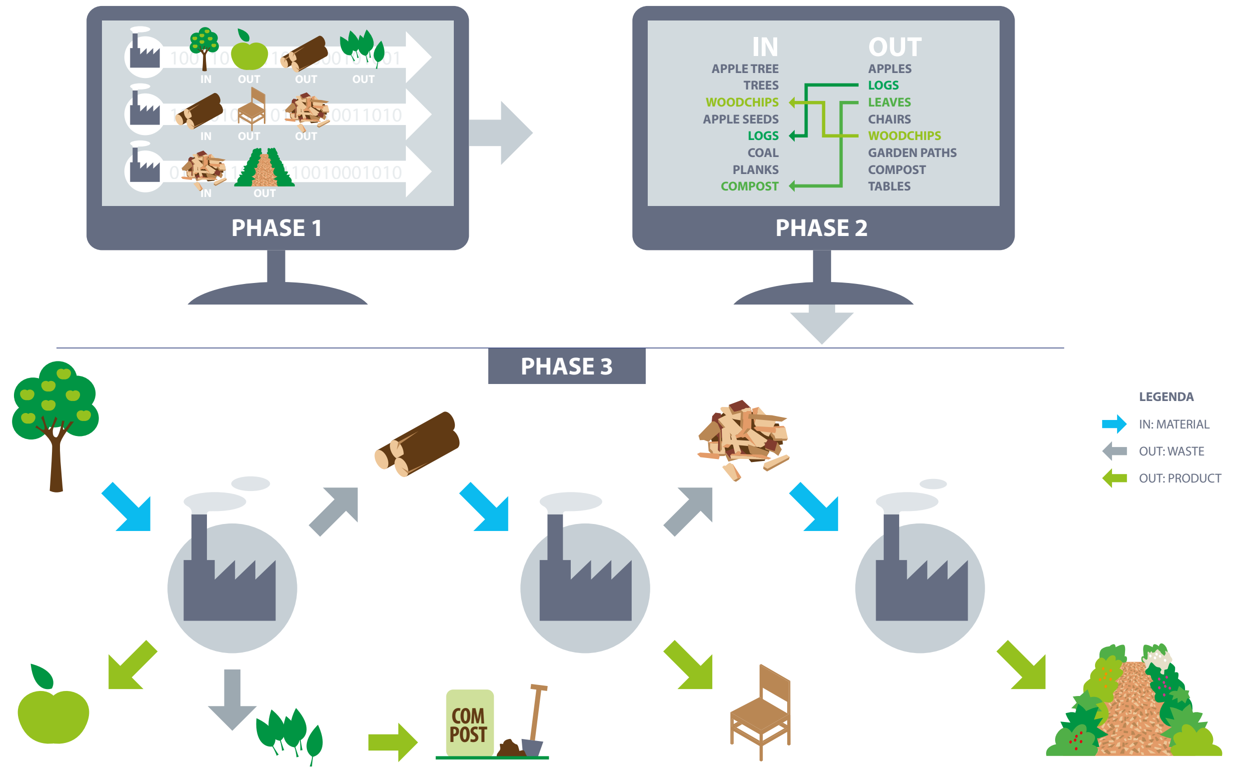
Bij Case 1, 3, 4 en 5 is een tweede meting uitgevoerd om te bekijken wat het effect is geweest van de gegeven feedback aan de uitvoerders. De eindmetingen vonden rond de oplevering plaats, nadat de uitvoerders de tips uit de feedback ter harte hadden genomen. Na navraag te hebben gedaan bij de uitvoerders en zelf vier cases te hebben gecontroleerd, bleek 71,7% van de tips daadwerkelijk opvolging te hebben gekregen. In het geval van Case 1 is de gemeten luchtvolumestroom gereduceerd met 67%, waarbij notabene ten tijde van de eindmeting het niet mogelijk was om het ventilatierooster van het dakraam boven de hal te sluiten. Voor Case 3 is de reductie 22%. Bij Case 4 en Case 5 was de reductie respectievelijk 41% en 65%. Dat is dus voor deze vier cases een gemiddelde reductie van 49%. Bij Case 6 is eveneens een tweede meting uitgevoerd, maar ditmaal door een andere partij. Deze meting gaf een resultaat van 0,45 dm3/s per m2 oftewel een verbetering van 24%. Bij deze tweede meting werd het ventilatiesysteem echter niet ter plaatse van de dakdoorvoer met opgeblazen ballonnen afgesloten, maar ter plaatse van de ventilatieopeningen in de woning. De blower door werd daarnaast in de voordeur geplaatst in plaats van één van de twee tuindeuren aan de achterzijde van de woning. Deze twee veranderingen in de uitvoering van de meting zullen enige invloed hebben op het verschil.

Er zijn in het verleden door het toenmalige SenterNovem in kader van het E'novatie programma al veel luchtdichtheidsmetingen uitgevoerd. Na circa twee decennia zijn het nu steeds vaker de opdrachtgevende en uitvoerende partijen zelf die om de zogenaamde blower door tests vragen om de luchtdichtheid van gebouwen te testen. Deze partijen zijn via email, oproepen op websites en oproepen in vaktijdschriften benaderd om de meetrapporten die zij in hun bezit hebben te delen met de Universiteit Twente en de Technische Universiteit Eindhoven. Deze oproepen hebben er toe geleid dat een database kon worden opgesteld met daarin de meetresultaten van meer dan 300 recent gebouwde woningen. Deze respons overtrof onze verwachtingen, waardoor het invoeren van de woningen langer duurde.

Op 2 en 3 februari zijn onafhankelijk van elkaar drie luchtdichtheidsmetingen uitgevoerd op een duurzaam gebouwde vrijstaande woning in Sterksel. De wijze van meten en de resultaten van de metingen zullen met elkaar worden vergeleken.

Op deze manier verwachten we meer inzicht te krijgen in hoeverre de resultaten van luchtdichtheidsmetingen met behulp van een blower door test kunnen worden gereproduceerd. Alle drie de metingen zullen op beeld worden vastgelegd. De luchtdichtheidsmeters zal worden gevraagd de luchtdichtheid van de woning te meten op basis van zowel onderdruk, als overdruk. Daarnaast worden ze gevraagd om een fotorapportage te maken van de lekken die zij zelf constateren in de woning.

De resultaten van de eerste deelstudie, te weten de veldstudie, zijn beschikbaar en zullen worden gepubliceerd door TVVL Magazine. De resultaten van de deskstudie en het vergelijkend praktijkonderzoek laten helaas nog even op zich wachten. De interesse naar dit onderzoeksproject "Impenetrable Infiltration" vanuit het werkveld van luchtdichtheidsmeters en de aandacht vanuit de media is bemoedigend en heeft ons blij verrast. We hopen dat deze interesse blijft en dat de nu uitgezette onderzoekslijnen kunnen worden gecontinueerd. Geïnteresseerde partijen om het vervolgonderzoek (financieel) te ondersteunen kunnen uiteraard contact blijven opnemen met de projectleider van dit onderzoek.



INDUSTRIAL SYMBIOSIS SOFTWARE

Bedrijven gaan tegenwoordig vooral lineair om met hun materialen. Grondstoffen komen binnen, worden verwerkt tot producten en hun afval wordt afgevoerd. Binnen één bedrijf ziet dit er logisch uit, maar in een systeem van meerdere bedrijven is te zien dat dit efficiënter kan. Als het afval van een bedrijf gebruikt zou worden als grondstof door een ander bedrijf, ontstaat er industriële symbiose. Daardoor worden er minder grondstoffen verbruikt en worden bruikbare restmaterialen niet verspild.

Om bedrijven te helpen bij het zoeken naar partners voor zulke uitwisselingen, is de software InduSym ontwikkeld. Met de software kunnen bedrijven hun grondstoffen en restmateriaal invoeren in een database. Een algoritme doorzoekt deze database en presenteert in een rapport de kansen om te komen tot een symbiotische uitwisseling van reststromen.

InduSym is een online software die ontworpen is om de vraag naar grondstoffen en het overschot aan restmateriaal van bedrijven bij elkaar te brengen. De software maakt het voor bedrijven zo eenvoudig mogelijk om de grondstoffen die ze gebruiken en de materialen die ze overhouden in te voeren in een database. Indien gewenst kunnen bedrijven meer informatie over de materialen geven, wat het eenvoudiger maakt voor andere bedrijven om in te schatten of ze een goede partner zijn voor industriële symbiose. Dit kan door middel van een nummer uit de Europese afvalstoffenlijst (Euralcode), omschrijvingen en tags. Ze kunnen bovendien alvast een indicatie geven over de financiële overeenkomst die ze willen sluiten, bijvoorbeeld of de reststroom gratis aangeboden wordt, of dat ze er een betaling voor verwachten.

Met de ingevulde informatie zoekt een algoritme in de database naar overeenkomsten met andere bedrijven. Als er een match tussen reststroom en grondstof gevonden wordt, kunnen de bedrijven met elkaar in contact treden om te onderzoeken of deze in de praktijk kan worden gebracht als symbiotische uitwisseling. Om de software eenvoudig, laagdrempelig en efficiënt te houden, zijn de matches betrekkelijk algemeen. Materiaaleigenschappen zoals temperatuur en volume, of proceseigenschappen zoals continu en batchgewijs kunnen in de omschrijving vermeld worden indien ze naar verwachting relevant zijn, maar dit is niet verplicht. Deze meer gedetailleerde informatie kan altijd nog aangevuld worden wanneer er match geïdentificeerd is en de intentie er is om deze in de praktijk te brengen. Dit voorkomt dat er veel tijd en moeite wordt gestopt in het omschrijven van materialen waar geen match op gevonden wordt.

De software kijkt naar matches tussen de bestaande bedrijfsprocessen, maar het is voor bedrijven ook mogelijk om zelf in de database te zoeken naar materiaalstromen waar nog geen match voor gevonden is. Dit is bijvoorbeeld handig bij het zich oriënteren op het aanbod aan lokale reststromen en het zoeken naar nieuwe mogelijkheden om de bedrijfsprocessen te veranderen of uit te breiden.

De software is tevens inzetbaar voor het analyseren van bedrijventerreinen omdat ermee in kaart wordt gebracht welke reststromen er beschikbaar zijn en naar welke materialen veel vraag is. Hier kunnen vervolgens ook projecten uit voortkomen. Als er bijv. veel biomassa beschikbaar is, kan overwogen worden een biomassacentrale te bouwen. Als er juist een grote vraag blijkt te bestaan naar een bepaald type grondstof, kan een bedrijf met zulke reststromen aangetrokken worden om zich op het bedrijventerrein te vestigen.

Interviews

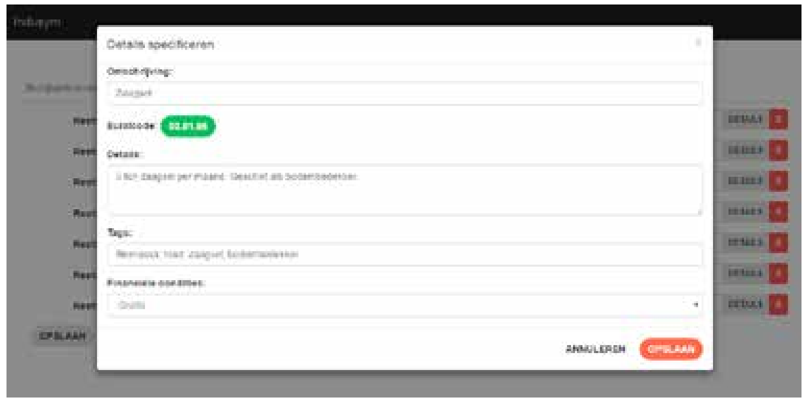
Om te komen tot een ontwerp dat zo veel mogelijk is toegespitst op de wensen van bedrijven, zijn interviews gehouden met bedrijven die zich aangesloten hebben bij de Helmonds Energie Community. Er werd met name gevraagd welke functionaliteiten voor hen belangrijk zijn en welke aspecten hen zouden kunnen belemmeren bij het komen tot industriële symbiose.

Bij bedrijven is winst vrijwel altijd de hoogste prioriteit. Ze beseffen echter wel dat als ze niet duurzaam handelen, ze op den duur klanten verliezen en buiten de markt komen te staan. De belangrijkste voordelen die de software hen dus biedt zijn de mogelijkheid om goedkopere grondstoffen te vinden en goedkoper van hun restmateriaal af te komen. Bovendien helpt het hun na te denken over hoe ze omgaan met hun afval en verwachten ze dat uit de verhoogde samenwerking op het bedrijventerrein ook andere voordelen voortkomen. De software bespaart hen dus geld, maakt ze socialer en duurzamer en verbetert daarmee hun imago.

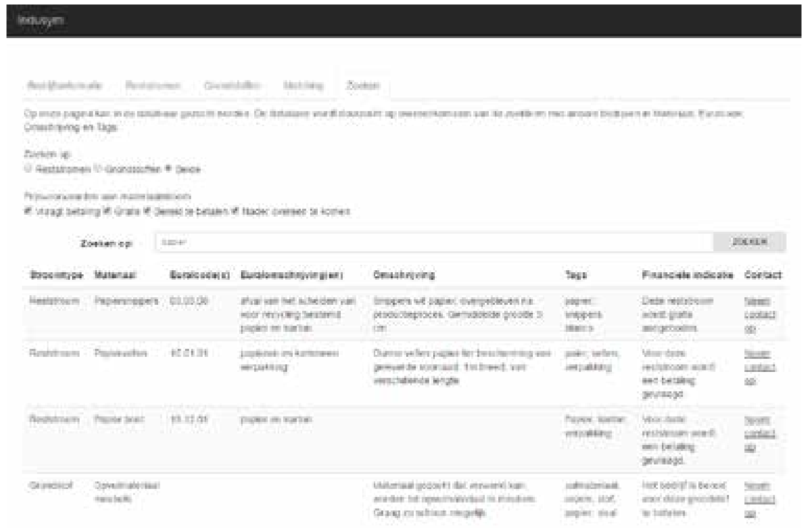
De drie belangrijkste voorwaarden voor bedrijven om gebruik te maken van de InduSym-software waren dat de matches wel financiële kansen moeten bieden, er vertrouwelijk met gevoelige informatie omgegaan moet worden en het gebruik ervan niet te tijdrovend moet zijn.

Bij de vraag naar welke randaspecten het belangrijkst zijn voor de bedrijven, bleek dat vertrouwelijkheid en anonimiteit van de informatie aanzienlijk minder belangrijk zijn dan een eenvoudige, effectieve software die hen mogelijkheden biedt om geld te verdienen en te besparen. De bedrijven zijn dus bereid informatie over hun processen te delen en optimistisch over de kansen die de InduSym-software biedt.

InduSym software: Invoer van reststromen



InduSym software: Specificatie van de reststroom



People, Planet, Profit

Industriële symbiose is dan ook goed voor zowel het milieu, mensen en de portemonnee, in lijn met het duurzaamheidsprincipe People, Planet, Profit. Door de symbiotische uitwisselingen verbruiken de bedrijven minder grondstoffen en wordt de waarde die nog in restmateriaal zit niet verspild door het bijvoorbeeld meteen te verbranden of te gebruiken als landvulling. Ook wordt het transport van deze materialen lokaler, wat eveneens goed is voor het milieu. Op termijn zou een bedrijventerrein zelfs zelfvoorzienend kunnen worden door de bedrijven op elkaar af te stemmen en bedrijven aan te trekken die de industriële symbiose bevorderen.

Uiteraard is dat ook goed voor de werkgelegenheid. Door het aangaan van samenwerking tussen de bedrijven, wordt hun verbondenheid met hun bedrijventerrein bovendien groter en zullen bedrijven zich er langer vestigen. Dit leidt tot een stabielere situatie. Als bedrijven met elkaar in gesprek gaan over materiaaluitwisselingen, kan dit ook leiden tot samenwerking en initiatieven op andere vlakken.

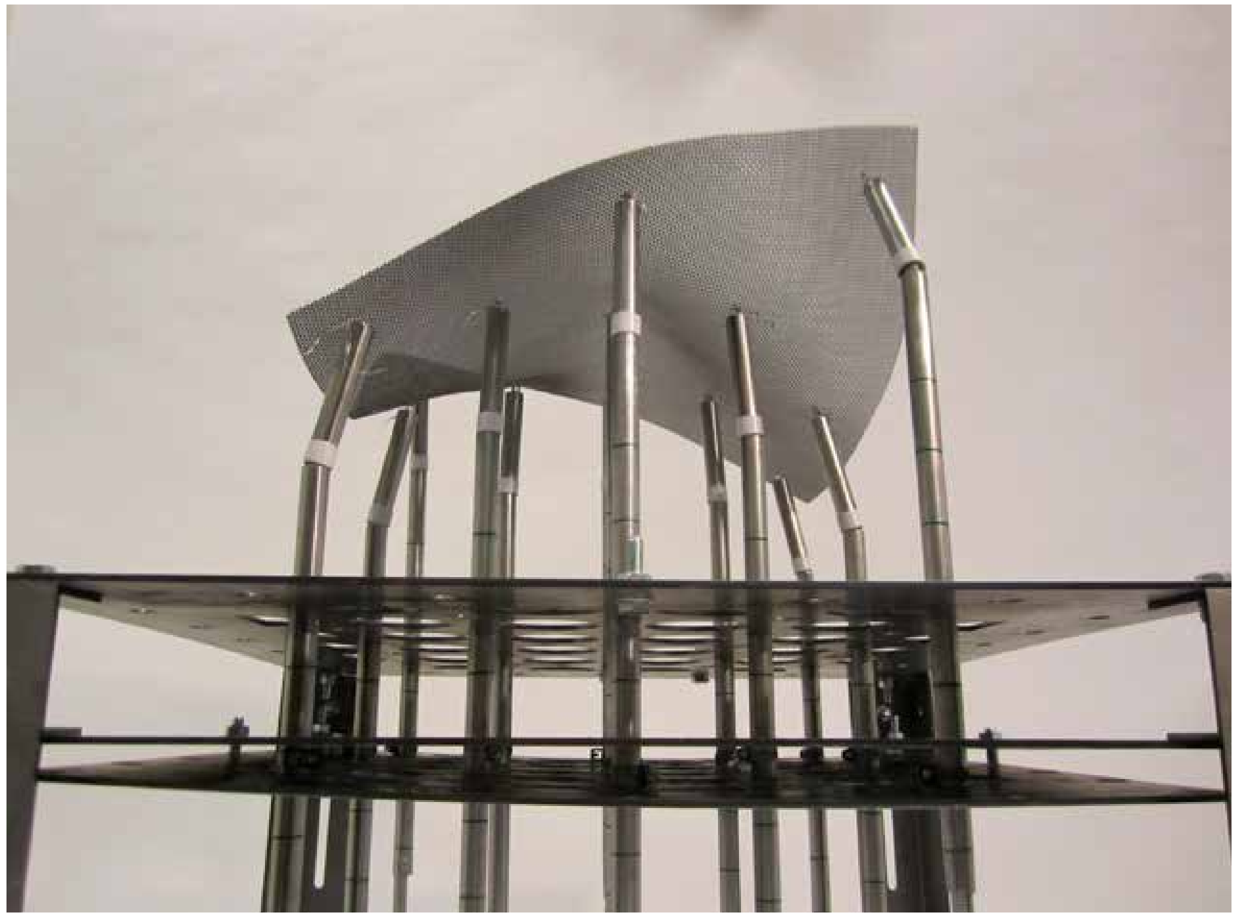
Bedrijven die nu nog veel moeten betalen voor het afvoeren en verwerken van hun reststromen, kunnen er straks veel goedkoper of gratis van af komen, en in sommige gevallen zelfs geld aan verdienen. De bedrijven die deze reststromen afnemen hebben op hun beurt een duurzame en goedkopere bron van grondstoffen.

InduSym

Na een jaar onderzoek, ontwerp en ontwikkeling, is de software InduSym nu voltooid. Als eerste stap naar een duurzamere situatie en meer circulaire economie zal deze software gebruikt en doorontwikkeld worden op de bedrijventerreinen die aangesloten zijn bij de Stichting Bedrijventerreinen Helmond.

Eindhoven Universty of Technology
Immanuel Geesing MSc.,
prof.dr.ir. **Bauke de Vries**

Stichting Bedrijventerrein Helmond
Frits Rutten



KINE-MOULD

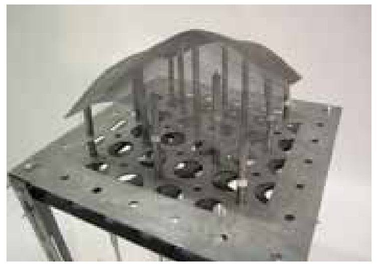
The Kine-Mould is a development that makes it easier to manufacture building elements with complex geometry. Since June 2014 the team has been working on a range of s olutions and prototypes. Various building materials have been investigated such as concrete, glass and plastic composites.

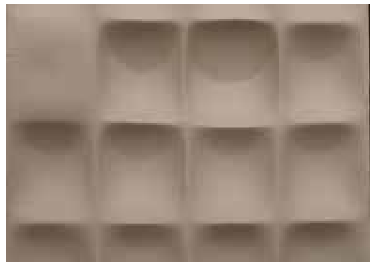
In a joint effort of TU Delft and TU Eindhoven the following prototypes were designed and built:

1. One for thermoplastic polymers
2. One for concrete elements
3. One for glass elements
4. Several for inflatable mould surfaces

Students carried out a significant part of the work. Companies were involved in the manufacturing process of the prototypes and application of the results.

If a thin polymer plate can be thermoformed into the correct geometry, this plate can be used as formwork for concrete or directly as a façade cladding panel. A closed two-face mould with closed edges is needed when using it as formwork. After hardening the concrete, the polymer plate can be removed and recycled. Two principles for deformation were investigated; thermoforming with gravity and with vacuum. For thermoforming a thermoplastic panel edge is clamped by flexible edges on which actuators are attached. After heating the thermoplastic polymer above its glass transition temperature, the edge can be deformed by setting the actuators at desired height. The middle section of the panel is supported by a





flexible layer, which can be manipulated by applying various tensions. The second principle relies on vacuum forming of thin acrylic plates. Here an air pressure difference is used after heating the thermoplastic to the proper temperature to control the exact edge shape. After cooling down to room temperature a two-face mould is constructed in a frame of edges, which can be filled with concrete. Since very thin plastic sheets are used, fluid or particles are needed to support the sheets under the concrete pressure.

Earlier Projects

The wish to create curved architectural glass elements has a history at both universities. At Delft, Dr. Karel Vollers was one of the first to succeed in manufacturing double-curved glass for architectural applications with a forerunner of the current flexible mould. At Eindhoven, Arno Pronk has been working on this topic for several years. In an earlier TU/e project students had already investigated the option to construct a small glass dome of double curved double glass units, joined together with vacuum-infused structural resins. This research projects presented the opportunity to align forces and knowledge to develop a state-of-the-art prototype and analyse the process in a more detailed manner.

Challenge

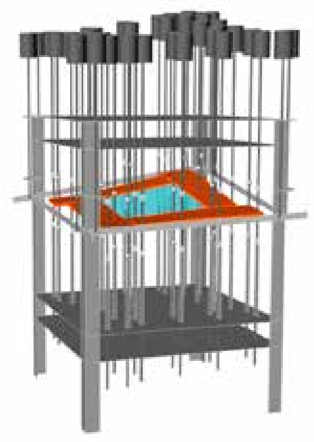
The forming of curved glass is as challenging as it is promising. If successful, it opens a wide range of promising possibilities: imagine shell structures consisting of load-bearing glass elements or think of hybrid building envelopes consisting of partially glass and concrete elements. Challenging however since glass is a brittle material and residual stresses after deformation to a large extent influence the structural behaviour and reliability of the curved glass element. Finally also the manufacturing process at high temperatures is challenging, since it requires heat resistant equipment.

Prototype

After some initial experiments at small scale (Figure 5), a larger prototype was constructed for bending glass with accurate dimensions in an oven. Two methods were tested: 1) the 'pizza-shovel' method, that pre-heats a glass panel wrapped in an insulating blanket, and then, after taking it from the oven with a pizza-shovel, draping and pressing it into its final, curved, shape on top of a pre-installed flexible mould. 2) the in-oven draping method: put the initially flat glass panel together with the flexible mould in the oven, and heat it until the correct shape can be formed with the plastic glass sheet. After a careful annealing process, the panel will have the correct curved shape.

The prototype contains a mesh of elastic steel which is supported by a grid of 5 x 5 actuators is suitable for both methods. The actuators can be adjusted vertically in the desired height position, and allow horizontal displacement of the tips. An essential characteristic of the steel mesh is that the grid size and wire diameter are chosen in proportion to the actuator distance, as well as that it allows in-plane shear deformation.

Before the start of the 3TU Lighthouse project, a small-scale prototype existed of the flexible mould for concrete, using a grid of flexible strips as interpolating surface. This prototype showed very promising results, but the team was curious to investigate scale effects and manufacture larger concrete elements. A new and bigger prototype for the flexible mould therefor was designed and built to investigate the behaviour of the mould on larger scale (Figure 7). On a small scale, effects like buckling of the strips in the interpolating surface are not likely to occur. For larger surfaces, though, this effect could potentially become more significant.



Fluid mould concept

The smoothness of the final panels is influenced by small details in the design of the mould. Dimensions and connections needed to be designed carefully to obtain accurate results. Apart from accurate the mould must be robust to function well within a concrete factory environment. Simple, robust and easy to repair solutions are key to the success of the mould. A finished prototype was transported to a concrete factory to gain more experience in the production process. Based on these experiences a design for a professional version is made which will be used for first projects in practice.

The principle of deformation after casting brings along questions regarding the concrete: What is the right moment of deformation? What is the effect of the deformation? How can the concrete be reinforced? Apart from the design and assembly of the larger prototype, these aspects have been investigated as well in the PhD research of Roel Schipper that will be finished shortly. Finally, also a computational model has been worked out to predict the effect of certain parameter choices, such as actuator spacing, strip thickness and elasticity, etcetera. This work is ongoing and will need further development.

Instead of realizing a smooth interpolation surface, additional shape control or play with element texture could be realized by making parts of this surface inflatable very locally. This could result in architecturally interesting textures, and furthermore could lead to a technology that opens new possibilities. In his Master's thesis project that was already on going at the start of the 3TU Lighthouse project, Mitchell Janmaat now had the chance to carry out some experiments with various inflatable mould surfaces.

Result

The 3TU Lighthouse project "Kine-Mould: material efficiency using a flexible kinematic mould system" has resulted in a range of coherent prototypes that demonstrate the feasibility of this manufacturing method for various architectural building materials. At the "Week van de Bouw" in February 2015, the prototypes will be shown. In the summer of 2015, more results and also elements produced with the moulds will be presented at the IASS2015 conference and exposition (see IASS2015.org Scientific publications will be written to give more in-depth descriptions of the results, including validation and testing. The work will be continued since many new ideas and possible solutions are waiting for further exploration as well as cooperation with industry. Further industrial partners are invited to contact us and discuss the possibilities.

Delft University of Technology
ir. **Roel Schipper,**
Peter Eigenraam MSc.,
Matteo Soru MSc.,
dr.ir. **Steffen Grünewald,**
Ivan Gavran, Mattias Michel

Eindhoven University of Technology
ir. **Arno Pronk,** ir. **Dick Erinkveld,**
Hisham El Ghazi, Mitchell Janmaat
Tobi Lusing, Erwin van Rijbroek,
Niek Schuijers, Martijn Verboord,
Robin Versteeg

The Leafroof prototype exhibited at the DDW 2015

LEAFROOF

The 3TU Lighthouse Leafroof project focuses on creating a roof design, inspired by the natural shape of leaves. Each of the leaf-shaped shingles incorporates the Luminescent Solar Concentrator (LSC) technology, which enables the system to "trap" solar irradiation, concentrate it to a much smaller area of PV cells and thus harvesting energy. This approach allows more freedom of building orientation and roof inclination compared to conventional PV systems. This project has successfully demonstrated a "leaf roof" prototype including feasible solar energy collection technology that also allows aesthetic design considerations. The work has been carried out by the project partners from the Building Lighting group at the Eindhoven University of Technology (TU/e) and the Industrial Design Engineering group at University Twente (UT). TU/e was responsible for the development of the prototype while UT carried out simulations towards optimization of the design. The collaboration has been set up to establish an active interaction between the participating groups. Both, simulations and lab measurements impacted the design of a first prototype. The project concluded with a successful proof of concept. The prototype was turned into a demonstrator that was exhibited at the Dutch Design Week 2015 in Eindhoven.

Luminescent Solar Concentration

Luminescent Solar Concentration (LSC) is a concept for harvesting solar energy that is comprised of a transparent shape acting as a lightguide with a large top surface.

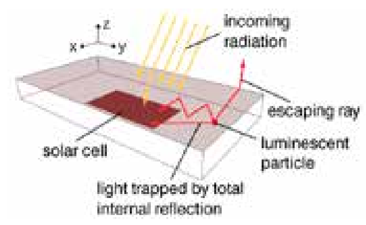


Figure 1. Working principle of an LSC taken from [1]

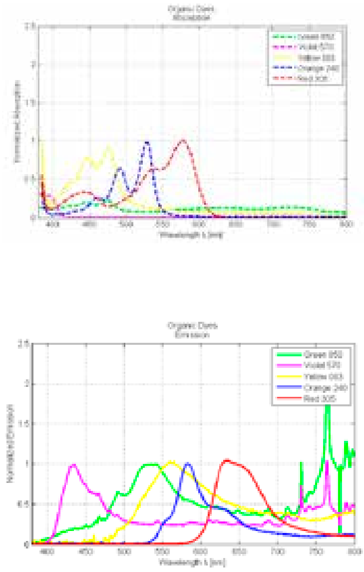


Figure 2. Normalized spectral absorbance (left) and emittance (right) of four different dyes

Figure 3. Photo of the final prototype: design (left) and photo of a complete tile (right)

This lightguide consists of a material with a refractive index higher than air and containing luminescent material, usually called 'dye'. Photons originating from solar irradiance, that enter the LSC get absorbed, subsequently re-emitted at longer wavelengths and next scattered by the dye. A large fraction of the re-emitted radiation gets trapped in the lightguide as it undergoes total internal reflection at the material's surface. Because the re-emitted radiation has longer wavelengths there is hardly any secondary interaction such as re-absorption with the dye. The trapping is interrupted at the interface between the lightguide and an attached solar cell, where the photons get converted into electricity (see figure 1) [1].

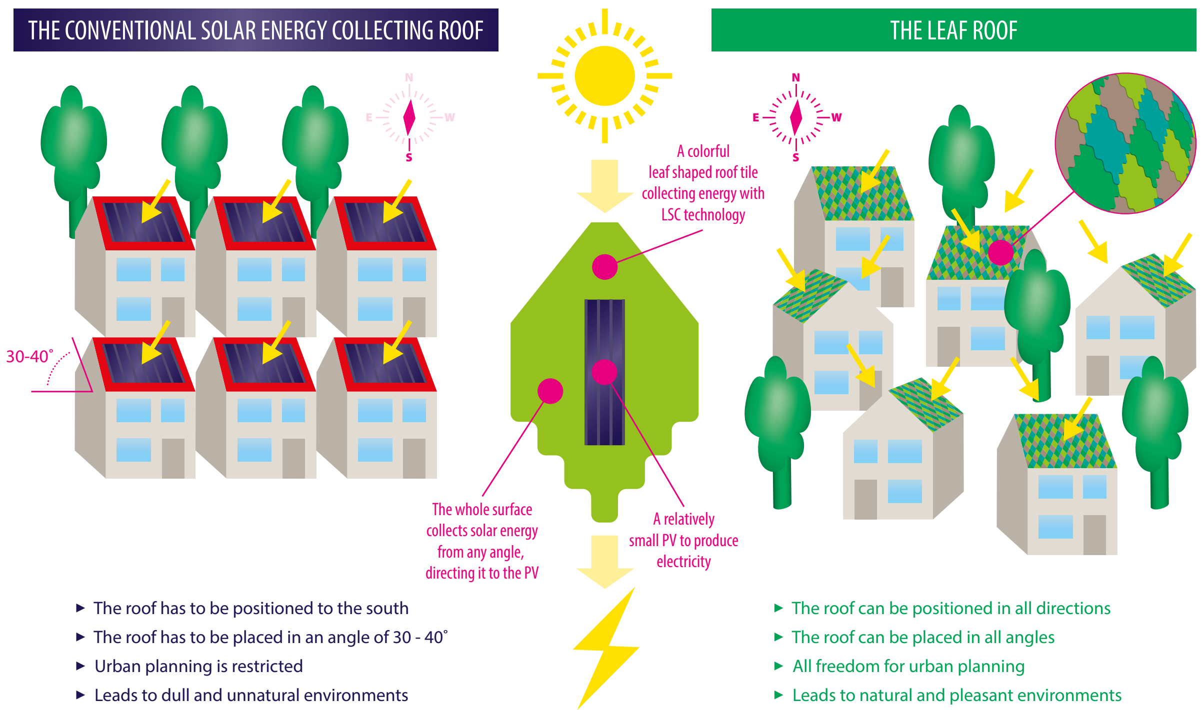
Simulations

In order to identify the most suitable features of an LSC for the leaf tile, several numerical simulations has been carried out by UTwente. Three-dimensional models of waveguides with optical properties of the materials involved have been simulated using ray-tracing software PVtrace and LightTools. It allows the performance evaluation of an optical system without the physical realization of the system itself. Also the absorption and emission curves of dyes can be input of both software packages. The evaluation of the influence on LSC harvesting performance looked into parameters such as:

- Shape of the tile
- Tile size
- Tile thickness
- Dye content, and the dye's absorption
- and emission characteristics
- Position and size of the PV cells

Two key simulation results will be addressed in more detail: the overall shape of the tile and the configuration of the PV cells. Table 1 provides an overview of the simulation results, which clearly point out an advantage of a rhombic shape over the other selected shapes with respect to photon density at the PV elements.

Subsequent investigation revealed that within the leaf-like shape, optimum arrangements for the PV cells are those that do not concentrate all PV cells in the center of the tile (see results overview in table 2).



Based on the discussion of the results and additional considerations with regards to potential ease of production, the configuration "Skewed parallel" has been chosen for the final design of the prototype.

Design of the Prototype

The first pre-concepts of the roof tiles were simple rectangles and evolved via a rhombus to a leaf shape. The first leaf-shaped tile was developed resembling the leaf of a European birch, a common tree in the Netherlands. In order to avoid a flat and dull impression of the roof, it has been thought that the tiles should have different colors. The composing pattern was designed with different colors, among them three different green variations.

Three guiding criteria are considered during design of leaf shapes:

- overlapping
- travelling distance
- positioning of solar cells

Overlapping of tiles must be reduced to enhance the energy performance (maximize the exposed surface hence light harvesting) and reduce costs (minimizing the overlap, hence material demand). The travelling distance of photons in the lightguide must not be longer than ten centimeters in order to minimize extinction (according to the exponential Beer-Lambert law for absorption of photons in matter) and re-absorption losses due to the dye. In order to maximize the utilization of light reflected from edges via reflective foils, the orientation of the solar cell relative to the LSC system is of importance. Different colors have

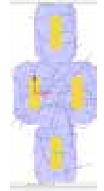
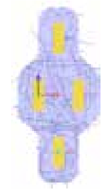
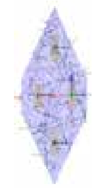
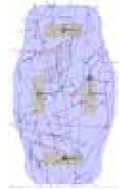
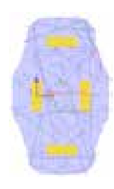
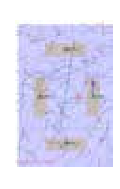
Config.	4 units fused	Saturn	Rhombic	Barrel	Barrel 80mm	Rectangle
Layout						
# harvested rays	18809	19562	20661	20305	18697	14882
Area	1290 cm²	1510 cm²	1380 cm²	1560 cm²	2110 cm²	1400 cm²
Photons per cm²	14.6	13.0	15.0	13.0	8.7	10.6

Table 1. Simulation results for variation of lightguide shapes for a four cells configuration

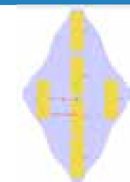
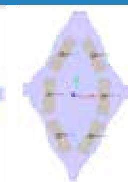
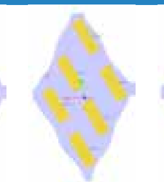
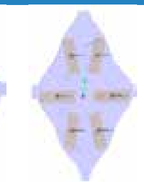
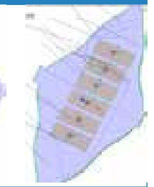
Config.	Veins parallel	Eye	Skewed parallel	Snowflake	Parallel
Layout					
# harvested rays	24246	24088	23708	23381	21222
Rays per cell	4041	4015	3951	3897	3537

Table 2. Simulation results of six cells configurations.

been chosen to realize the LSC leaf tile. The spectral absorbance and emittance for each color was measured and are shown in figure 2. One can see that according to the theory, the emission spectra are shifted to the infrared part of the irradiance spectrum, compared to the absorption spectra.

For the prototype design, a tile configuration consisting of 6 PV cells has been chosen. The total area covered by PV cells is then 312 cm2. Different configurations have been evaluated with regards to their efficiency by numerical simulations conducted by UTwente. The solar cells used are Sunpower C60 solar cells GEN C BIN J with 22,5% efficiency under Standard Text Conditions (STC).

During lab tests of prototypes it has been observed that dark elements such as PV cells concentrate lots of radiation and subsequently heat up their local surrounding leading to a temperature gradient with the plastic waveguide. This, in turn, creates small bends in the prototype. The resulting mechanical stress might lead to the breakage of the interface between cell and waveguide. To overcome this drawback a configuration was chosen that allows a greater distance between cells, as shown in Figure 3.

Eindhoven University of Technology
prof.Dr.-Ing. **Alexander Rosemann,**
ir.ing. **Guillaume Doudart de la Grée**,
ir. MEng. **Argyrios Papadopoulos,**
dr. **Michael Debije,**
ir. **Mark Cox, Riccardo Capperucci**

University of Twente
prof.dr. **Angèle Reinders,**
dr. **Zachar Krumer**

Municipality of Laarbeek
mr. **Frans van Zeeland**

The Leafroof Prototype

The leafroof prototype has been demonstrated at the Dutch Design Week.

References

[1] Doudart de la Gree, G.C.H., Papadopoulos, A., Debije, M.G., Cox, M.G.D.M., Krumer, Z., Reinders, A.H.M.E. & Rosemann, A.L.P. (2015). A new design for luminescent solar concentrating PV roof tiles. Poster : *42nd IEEE Photovoltaic Specialists Conference 2015* (PVSC-42), 14-19 June 2015, New Orleans, LA

[2] Rosemann, A., Doudart de la Grée, G., Papadopoulos, A., Debije, M., Cox, M., Reinders, A. and van Zeeland, F., Leaf Roof, *SPOOL, doi:10.7480/spool.2015.2.966*, 2(2), pp 21-23, 2015

THE LIGHTVAN

Een van de uitdagingen voor de gebouwde omgeving is dat er een sterke reductie van het energieverbruik nodig is. Daglicht heeft vele mogelijkheden om een goede energiebron te zijn wanneer sommige problemen, zoals verblinding en oververhitting, kunnen worden voorkomen. Naast een goede energiebron is daglicht ook nodig voor het biologische systeem van het menselijk lichaam, het hormoon systeem en het slaap-waakritme. Dat betekent bijvoorbeeld dat bij een goede daglichtomgeving kinderen beter kunnen presteren op school en senioren beter kunnen slapen en minder depressieve gevoelens zullen hebben.

Praktische daglichtonderzoeken worden meestal gedaan met proefpersonen die al op universiteiten en laboratoria aanwezig zijn, zoals de studenten en de medewerkers. Het is de vraag of conclusies getrokken uit dit type studies geschikt zijn om bijvoorbeeld goede basisscholen en senior woningen te kunnen ontwerpen en bouwen. Onderzoekers verwachten dat de ontwerpregels volledig kunnen verschillen voor deze specifieke gebouwen en hun gebruikers, omdat de zintuigen van mensen en de verwerking in de hersenen eerst op jonge leeftijd een ontwikkeling doormaken en later bij het ouder worden ook weer veranderen. Zo blijkt bijvoorbeeld dat senior ogen vier keer zoveel licht nodig hebben als die van jongeren en dat problemen met verblinding anders ervaren worden. Jonge kinderen en ouderen hebben vaak geen mogelijkheden om naar universiteiten te komen om proefpersoon te zijn bij laboratorium testen. Als we willen dat daglicht gebruikt wordt als een goede, gezonde en goedkope energiebron, dan moeten we gebouwen ontwerpen die visueel comfortabel zijn voor de gebruikers.

Dat vraagt om meer specifiek onderzoek met ouderen en kinderen als proefpersonen.

LIGHTVAN

Recent is een multifunctioneel mobiel lichtlaboratorium gebouwd in een transport auto, de LIGHTVAN. Deze LIGHVAN heeft een tweeledig doel: Met dit rijdend lichtlaboratorium kunnen we naar de leefomgeving van specifieke groepen mensen gaan, de kinderen en de senioren, zodat zij proefpersoon kunnen zijn bij specifieke leeftijdsafhankelijke lichtonderzoeken. In dit rijdende laboratorium is daartoe meetapparatuur aanwezig en ook een tafel en stoelen voor de diverse proefpersonen. Testen over luminantie- en kleurcontrasten zijn mogelijk, evenals 'licht en schaduw' patronen. Zelfs kleine oogtesten kunnen worden uitgevoerd. Daarnaast is de achterzijde van de bestelauto aangepast zodat bij geopende deuren allerlei innovatieve gevels getest kunnen worden. De LIGHTVAN kan naar verschillende locaties worden gebracht en gericht op diverse zon richtingen. Diverse passe-partouts zijn aanwezig voor verschillende maten van gevels, zodat bouwfysische metingen gedaan kunnen worden en proefpersonen hun voorkeuren betreffende comfort en gezondheid voor gevels kunnen aangeven.

Mobiel Lichtlaboratorium

De bouwfysica groepen van de Technische Universiteiten van Delft en Eindhoven hebben in een eerder stadium van onderzoek al pilotstudies in scholen, seniorenwoningen en verzorgingshuizen uitgevoerd, met bouwfysische metingen en vragenlijsten voor de gebouwgebruikers. Met het mobiele lichtlaboratorium kunnen we ook laboratoriumproeven en observaties gaan uitvoeren in de leefomgeving van kinderen en senioren, dus met de juiste proefpersonen. Daarnaast kunnen we alle leeftijdscategorieën van proefpersonen bevragen over het comfort en hun voorkeuren bij nieuwe innovatieve gevels. Dat zal meer mogelijkheden en betere onderzoeksresultaten geven.

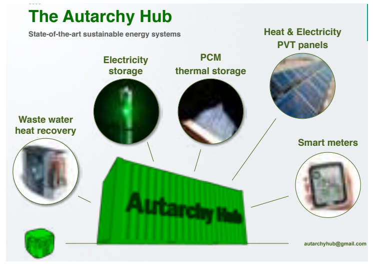
Met het 'LIGHTVAN' onderzoek beogen we het lichtontwerp voor gezonde scholen en moderne seniorenwoningen en verzorgingshuizen te optimaliseren met betrekking tot het gebruik van daglicht als een goedkope en belangrijke energiebron.

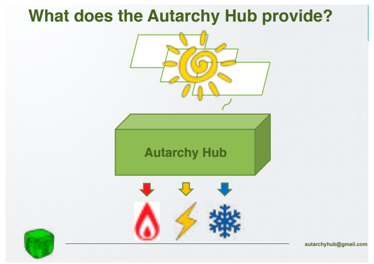
Delft University of Technology
assoc.prof.dr. **Truus Hordijk**,
Dr.-Ing. **Marcel Bilow**

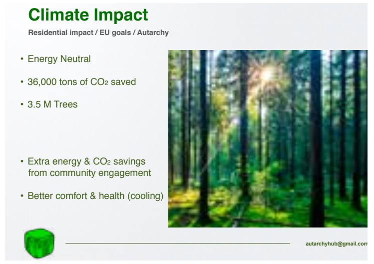
Eindhoven University of Technology
ir. **Marielle Aarts**,
prof.Dr.-Ing. **Alexander Rosemann**

A LIVING LAB

What is required from built environment enterprises to comply with the sustainability goals set by COP21 in Paris? Are the goals set by European Union for 2020 for new buildings or renovation of old buildings enough to tackle the built environment's impact on climate change? In order to reach the energy neutral built environment, new and renovated buildings should produce more energy that they consume, to compensate for existing buildings, for which there are no plans to get renovated. Such an approach should produce high margins for the built environment enterprises, either with the ESCO approach, or by higher selling prices, due to the reduced life cycle costs of their buildings. The society would also benefit by actively participating in the energy transition, by enabling energy efficient houses to reach positive energy margins by adapting their energy consuming behavior. This could also be translated to monetary savings. But how can the built environment enterprises to design and built positive energy buildings? Would the design for positive energy built environments in community level be more socially and financially attractive? A strategy towards the design of positive energy built environment has been developed using the Heijmans ONE communities as a case study.







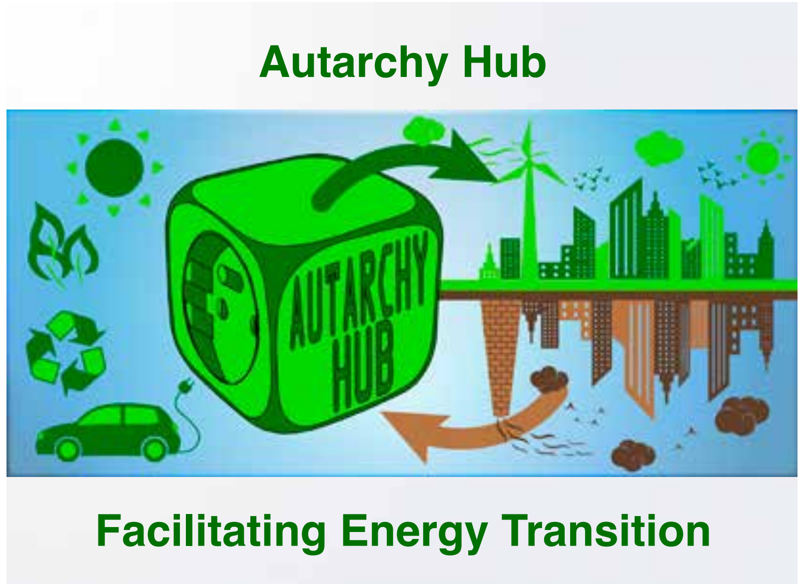
Project Scope

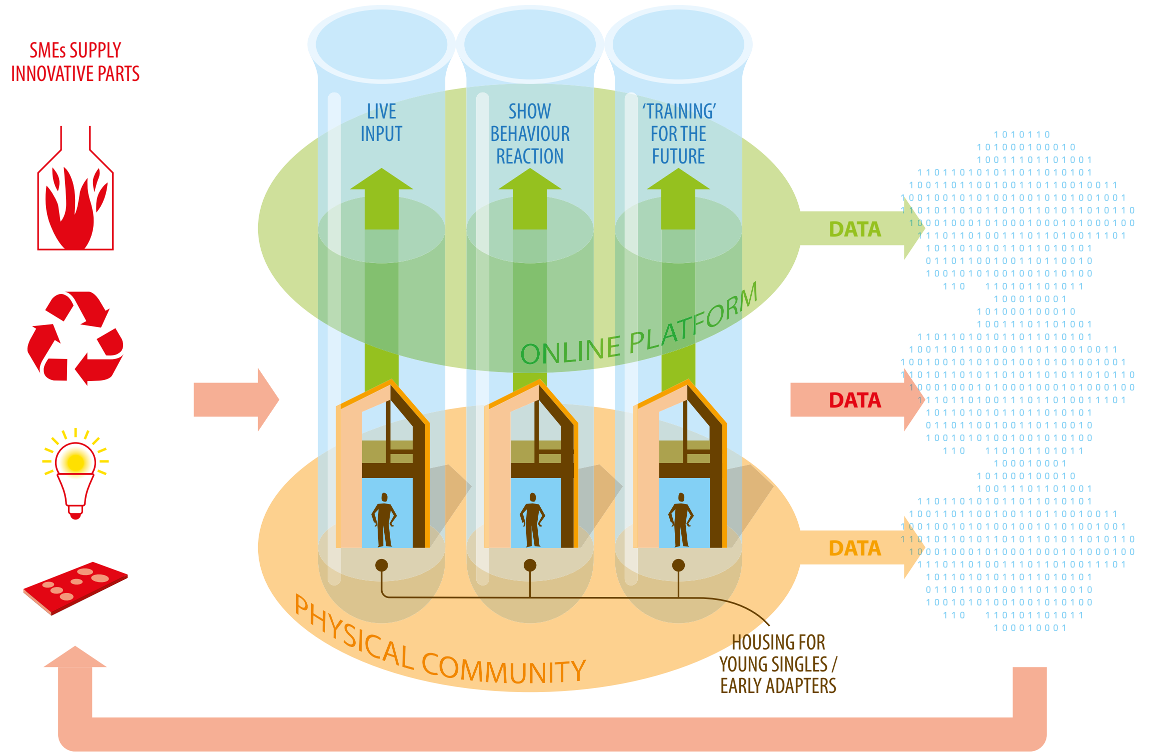
In this project, TU/e university researchers and Heijmans N.V. have formed a team, in order to link industry with research for the potential application of research outcomes in built environment development projects. It aimed to develop a strategy for the integration, implementation, operation and maintenance of new technologies and practices in the design of the built environment. An actual Heijmans built environment project, the Heijmans ONE communities, was chosen as a case study to perform applied research. The Heijmans ONE residence is a new product of living developed by Heijmans, aiming at young professionals who earn too much for social housing and too little for the free rental sector. It consists of a small prefabricated, mountable, temporary residence.

Goals and Results

One of the two main goals of this assignment were to develop a list of technologies that can be applied in built environment, and a strategy to pave the way towards the goal of the company to design and potentially construct a zero energy, or even positive energy (surplus energy balance), urban environment by 2020. To validate this strategy and especially regarding emerging technologies, the case study was introduced, in order to match the Heijmans ONE with a creative process towards the transition to sustainability.

The second main goal was to develop a business plan for the commercialization of the results of the applied research. For this, the idea of a living lab based on the Heijmans ONE residence where innovative technologies would be tested emerged. Ideally, these technologies would modularly attach to the building in a similar way to 'Phonebloks' flexible mobile concept. Following this concept, the "Autarchy Hub" idea evolved, which lead to the design of a centralized neighbourhood level energy service business case and business plan.





Results

To accomplish these goals, the milestones set were met:

- A detailed morphological overview of available or potentially available materials and technologies for implementation in the urban environment for district, building, and user level.
- An assessment of materials and technology; based on investment, operational and maintenance costs, if possible.
- A technology selection strategy for optimization of the design of buildings based on typology, functionality and realization criteria of technologies.
- A business plan for the development of a living lab for the Heijmans ONE community.

The successful completion of these milestones has allowed further development of the project's aim and a broader application of the formulated design strategy to other built environment projects. In detail, the following are the most important additional results of the project:

- A business law report for a company producing a neighbourhood level centralized CHP plant.
- The development of the design basics, requirements, criteria, and design optimization for the Heijmans ONE residence, producing 2 scenarios: the "Smart Off-grid Heijmans ONE"and the "Heijmans ONE SmartVille".
- A proposal for the renovation of RM3 Heijmans office complex, using the developed database with assessment of the proposed design scenarios.
- A proposal for the renovation of social housing residences, using the developed Matlab tool and database, with assessment of the proposed design scenarios.
- A detailed component sizing and pricing for the Heijmans ONE off-grid system and connection with two companies to realize the aforementioned project plan.
- Participation, reaching the national finals, in Climate KIC Launchpad NL competition with the 'Autarchy Hub' idea for neighbourhood level (centralized) Energy Service Company.
- A business plan for the development of an energy service/product Heijmans spin-off company called 'Autarchy Hub'.

Eindhoven University of Technology
ir. MEng. **Argyrios Papadopoulos**,
prof.dr.ir. **Bert Blocken**,
prof.dr.ir. **Pieter van Wesemael**,
prof.dr.ir. **Jan Hensen**,
dr.ir. **Pieter-Jan Hoes**,
dr.ir. **Mohamed Hamdy Hassan**,
dr.ir. **Ignacio Torrens Galdiz**,
Isabella Gaetani dell'Aquila d'Aragona, Maria Odete Magalhães de Almeida, Bas Giskes

Heijmans N.V.
Dick Timmermans, Gerard de Leede, Anneke Dalhuisen, Pim Katelaars

ESADE Business & Law School
Jordi Guasch Lopez

Field Study

During the period of this project, the first two Heijmans ONE residences were constructed and placed at Zeeburgereiland, Amsterdam. In one of these residences, different people would stay over the period of a few months, while the other was used for showcasing purposes. Then, following the development of the living lab idea, it was decided to install energy consumption plug load monitoring equipment in one of the two residences.

The installation of this measuring equipment allowed us to monitor and understand the energy consumption patterns of the Heijmans ONE and the most energy consuming appliances. In addition, the indoor temperature and humidity conditions were monitored, to distinguish the thermal comfort conditions in the residence.

Finally, the measurements were used to validate a building performance simulation TRNSYS model of the Heijmans ONE residence, developed by an MSc graduate in Building Services & Physics in TU/e, for checking the performance of the design tools and in depth optimization of the detailed design.

Conclusion

The project involved the development of both process and product innovation results. The process innovation is related to the development of initial design stage building optimization tools giving emphasis in the energy aspects. The product innovation is related to the development of the business plans for the living lab and the "Autarchy Hub", to be realized in 2016 in collaboration with TU/e and its Innovation Lab.

LUMINESCENT SOLAR CONCENTRATOR

A luminescent solar concentrator (LSC) is a device that has luminescent molecules embedded in a polymeric or glass waveguide to generate electricity from sunlight via a photovoltaic cell attachment. The LSC device can function in diffused light as well as direct light, and may come in a variety of colors, shapes and transparencies. Therefore, the LSCs can be employed both in small and large scale projects, independent on the direction or angle of the surface with respect to the sun. It also promises more freedom for integration in urban environments and design choices compared to the traditional PV systems.

Even though, the LSC offers many advantages over existing technologies, it has not yet been commercialized. To achieve this, proper understanding and exploration of not only technical aspects, but also insights into its presentation, design and appearance is needed.

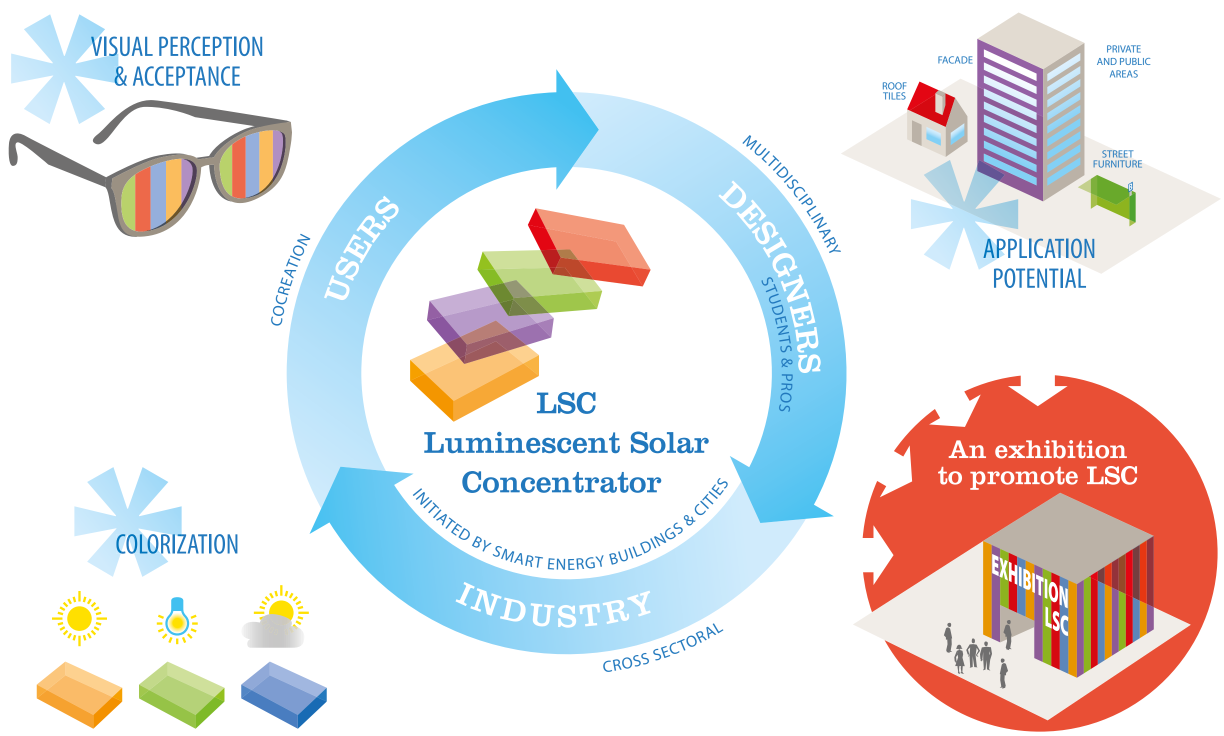
The aim of this Smart Energy Buildings & Cities (SEB&C) company assignment is to investigate the applicability of the LSC device in the built environment and to create a successful business case for a new product design that utilizes this technology.

The necessity of a paradigm shift emerged towards sustainable and smart cities due to the significant increase in the energy demand of buildings. The challenge is to increase renewable sources in the energy mix while designing aesthetic environments. Therefore, renewable energy technologies that can be well integrated in urban areas represent a great opportunity to help overcome this current challenge.

Smart energy, energy efficiency and use of renewable sources are key aspects to be considered nowadays and many innovative technologies need further exploitation to be commercially viable, such as the luminescent solar concentrator.

The research on solar energy conversion with luminescent solar concentrators (LSCs) was initiated in late 1970s; these first experiments aimed at solar energy conversion with florescent collectors to be used at greenhouses (Weber & Lambe, 1976; Goetzberger & W., 1977). Due to the shift from fossil fuel to renewable sources for energy generation and the emergence of solar energy technologies to improve sustainable development; research on LSC gained importance as it is a promising technology for integrated energy generation solutions in urban spaces. The working principle of LSC has not been changed from late 70s until now; nevertheless, the improvements of luminescent materials, solar cells as well as theoretical studies renewed the interest in the LSC technology. Several configurations with different dyes, mirrors, reflector coating and PV types have been investigated to increase the electrical performance.

Furthermore, various research groups throughout the world, including TU/e (Debije & Verbunt, 2011), have been investigating the energy performance of the LSC modules in order to create value that is feasible and competitive in the built environment market.



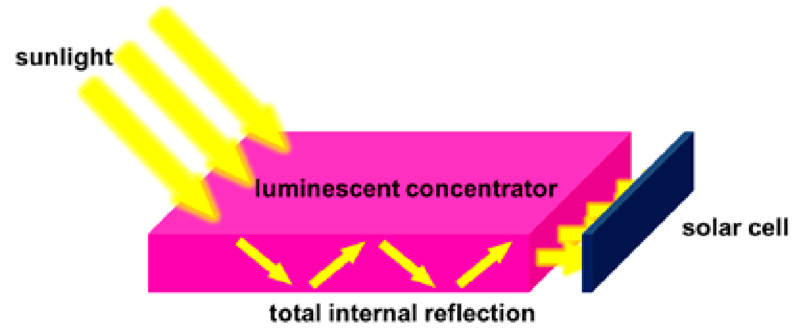
To create value, the product type is as important as the energy performance. This means we should think of designing products benefitting from the appearance of LSC while generating some energy. It was necessary not to see the electricity generation as the main target but an additional value.

Before selecting a product idea for further development, we followed a participatory approach to generate ideas about the possible application areas of the LSC device. Two co-creative workshops and an open innovation survey were executed to gather ideas about the applicability and visual perception of LSC with the participation of the SEB&C trainees, employees of Heijmans, two freelance designers and 83 surveyors.

Looking at the results gathered during this co-creative process, it can be stated that, participants perceive LSC as a technology that will help integrate renewable energy generation in urban areas. Exterior façade cladding, window glazing, public transportation waiting area, shading device and street lighting are some of the examples of application areas proposed by the participants. All the generated ideas gave us guidance to develop design concepts for three different LSC-based products, which have different value propositions for the built environment. One of these proposed design concepts was a small scale urban greenhouse that provides herbs and plants while generating some energy for its own use (lighting and water pumping for irrigation). This concept was called Re(d)Garden which was designed to work as a community garden in urban spaces. This design aimed at creating a social space that can be located at areas lacking vegetation while contributing to renewable energy generation, urban farming and rainwater harvesting to cope with the extreme rainfall events and floods.

Eindhoven University of Technology
Tugce Tosun-Uslu MSc.,
prof.dr.ir. **Jos Lichtenberg**,
dr. **Michael Debije**

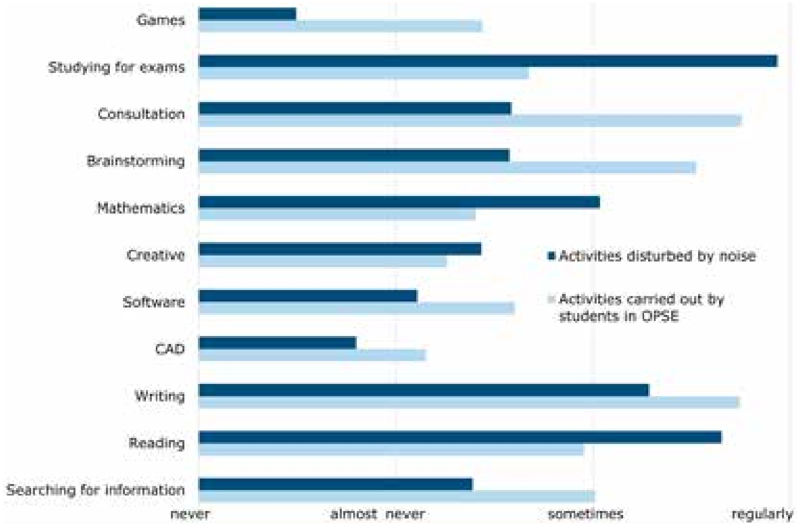
Heijmans Technology
Alma Krug, Stijn Verkuilen



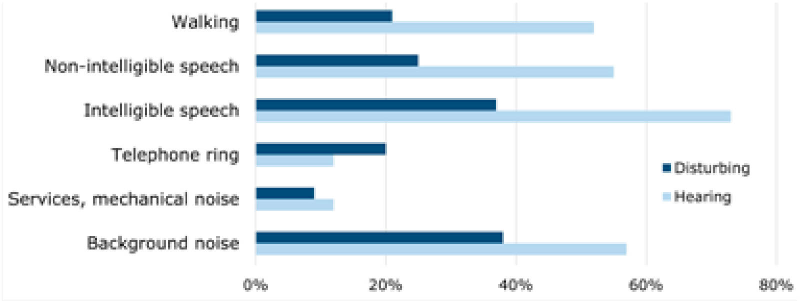
As a result of the explorations, we managed to develop LSC-based product concepts for various market segments. We can say that LSC-based products can be economically feasible with the integration of not energy intensive functions. If the technical performance of the LSC device is improved, we can expect to see LSC-based products in the energy and built environment markets in the near future.

References

[1] W. Weber and J. Lambe, "Luminescent greenhouse collector for solar radiation," Applied Optics, vol. 15, no. 10, pp. 2299-2300, 1976.
[2] A. Goetzberger and G. W., "Solar energy conversion with fluorescent collectors," Applied Physics, vol. 14, no. 2, pp. 123-139, 1977.
[3] M. G. Debije and P. P. C. Verbunt, "Thirty Years of Luminescent Solar Concentrator Research: Solar Energy for the Built Environment," Advanced Energy Materials, vol. 2, no. 1, pp. 12-35, 2011.



Student activities in open-plan study environment



Sound sources in open-plan study environment

NOISE IN OPEN-PLAN STUDY ENVIRONMENTS

Noise is one of the most annoying factors in open-plan work environments. This research focuses on the acoustics of open-plan study area in higher education. The goal of this study is to optimize the acoustic design of an open plan study environment to enlarge the well-being and (learning) performance of students. Laboratory experiments and field research will give insight in the relation between the acoustic parameters of an open-plan study area, the tasks and characteristics of the student and well-being and performance. The found relations will be translated into recommendations for architects and consultants to design better open-plan study areas.

Eindhoven Technical University
ir. **Ella Braat-Eggen**,
dr.ir. **Maarten Hornikx**,
prof.dr. **Armin Kohlrausch**

Avans Universty of Applied Sciences

NWO

OPTIMISING 3D CONCRETE PRINTING

The application of new Computer Aided Manufacturing (CAM), digital fabrication and additive manufacturing techniques in the construction industries is expected to bring major change to these industries. Driven by a foreseen reduction of construction time and labor cost, simplification of logistics and an increase of constructible geometrical freedom, many experiments are performed both at academia and in practice.

Beyond these economical and architectural objectives, digital fabrication in construction can be used to reduce the environmental footprint of the industry. The increased level of control offered by digital fabrication enables the use of advanced computational optimisation techniques. With these optimisation techniques buildings can be designed which, for instance, combine an optimal thermal performance with a minimum use of materials, while still complying with all codes and standards.

To fully utilise this potential of digital fabrication, the capabilities and limitations of the manufacturing process need to be taken into account during optimisation. By combining the concrete 3D printing knowledge of Eindhoven University of Technology, the optimisation expertise of the BEMNext lab at Delft University of Technology and software development by White Lioness technologies, the 'Optimising 3D concrete printing' Lighthouse project has made the first steps towards more knowledge on integrated optimisation and manufacturing.

Context

Additive Manufacturing (AM) techniques are employed to overcome limitations of traditional manufacturing in terms of precision and/or constructability and allow for application of digital fabrication on a multitude of scales and materials. The difference between an object on a designer's screen and the physical, manufactured artifact can be orders of magnitude smaller with an additive manufacturing powered process in comparison to a conventional manufacturing process.

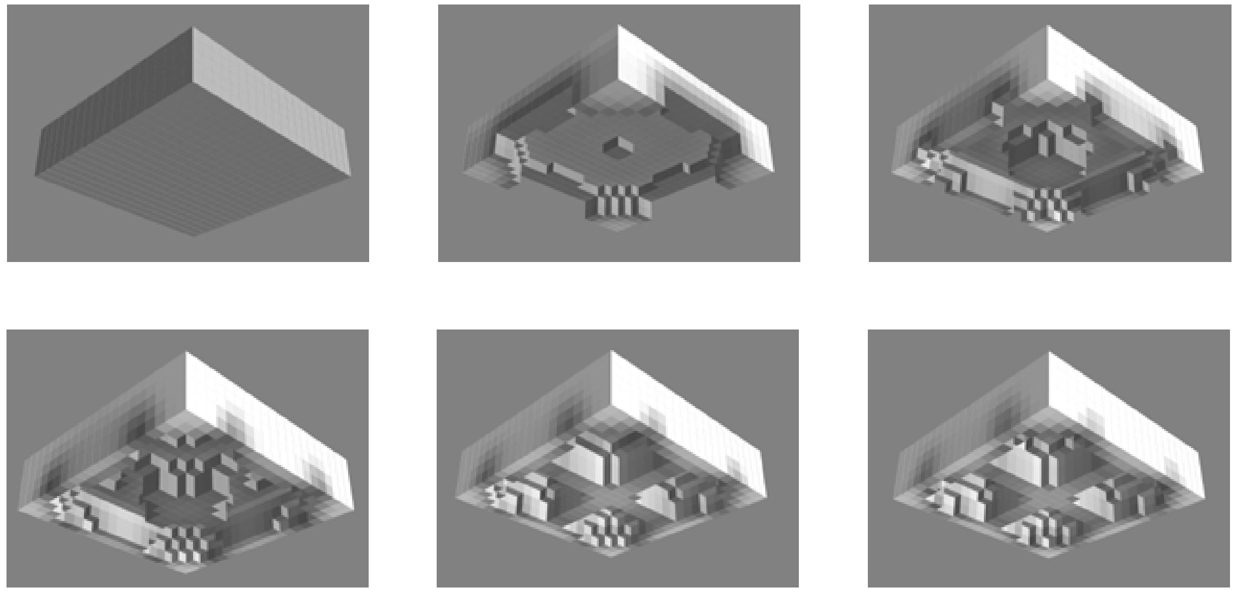
It is this narrowing of the gap between computational design and physical artifact which enables better use of advanced optimisation techniques in design. For years optimisation algorithms have been used to acquire the best performing designs, with respect to different metrics, whilst still complying with standards and regulations. A common example is a minimisation of material used, for which topology optimisation algorithms are well suited.

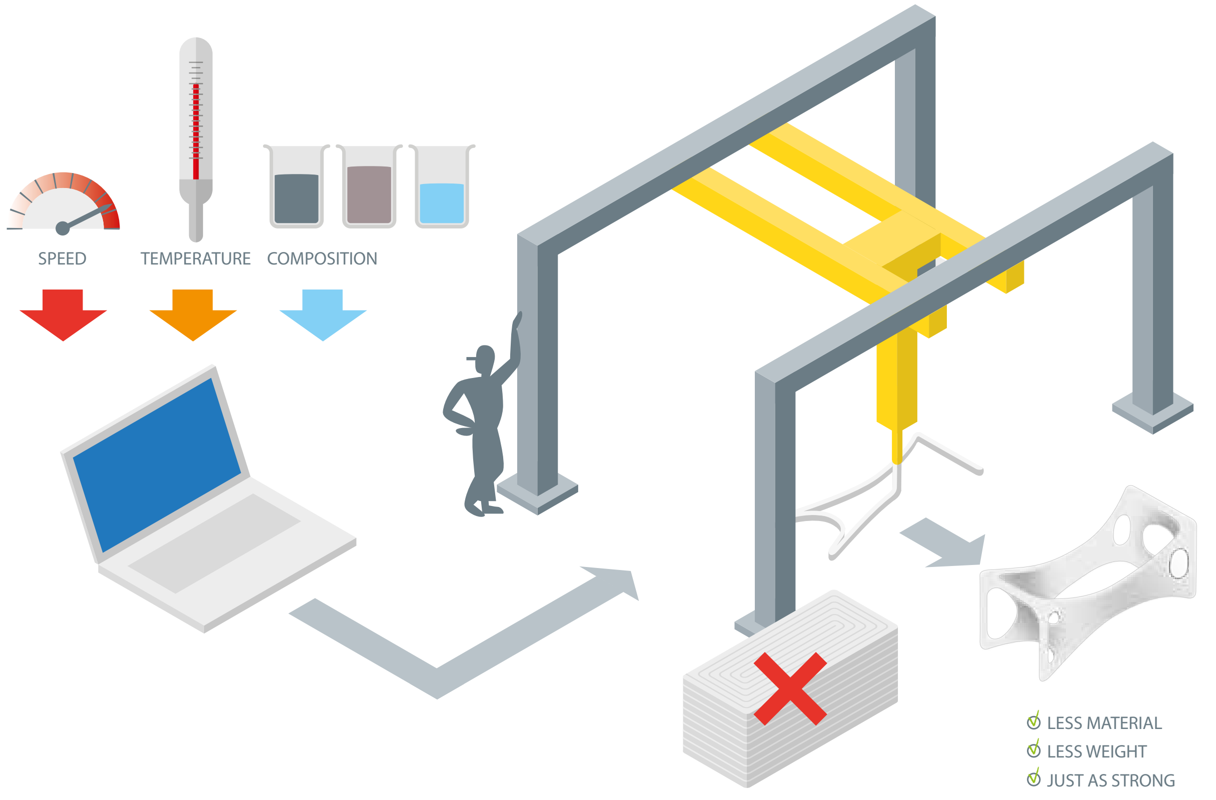
One of the main limitations on the widespread adoption of optimisation in the construction industries lies in the conditions on the construction site. As optimised designs often approach the boundaries of what is possible or allowed, they are more vulnerable to construction errors. Additionally, the scale on which the geometry can be optimised is limited by the often manual process employed on the construction site.

By use of additive manufacturing in construction some of the main limitations on use of design optimisation can be removed, enabling the design and construction of further optimised, more environmentally friendly buildings and infrastructure.

Project

The 4TU.Bouw Lighthouse project on "Optimising 3D concrete printing" aims to make the first steps towards an environment in which geometries can be optimised whilst taking the properties and limitations of a 3D concrete printer and the resulting material properties into account. These additive manufacturing specific features are key to ensuring the optimised geometry can indeed be printed and that the resulting artifact behaves as expected. Once again, as optimised geometries are often on the limit of the materials potential, the correctly modelled behaviour is even more important in optimisation than in conventional design techniques.





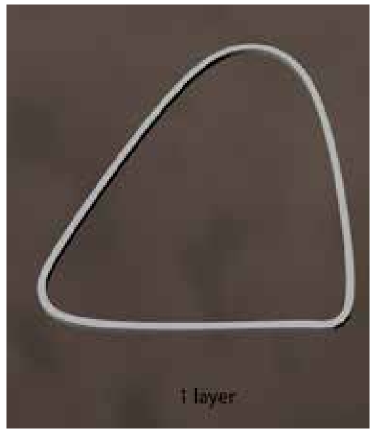
Printer Properties

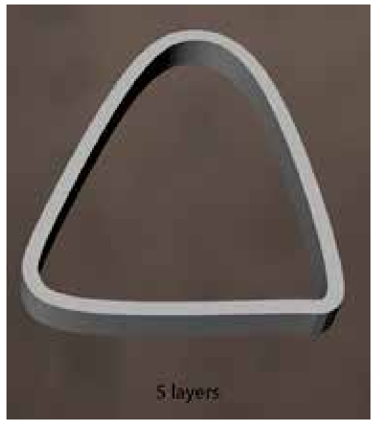
Whilst additive manufacturing has an increased geometrical freedom in comparison with many conventional construction techniques, there still are boundaries to what can and cannot be printed. In the "Optimising 3D concrete printing" project the following aspects are identified and considered:

- Vertical cantilevering angle between layers
  Without the use of a support material the layers can only cantilever a few degrees, both in the printing direction, as well as perpendicular to that direction.
- Printing direction
  In this project, the printing direction is kept constant. Layers are printed next to each other and on top of each other.

- Nozzle width and layer height
  The nozzle width and the layer height can be chosen at the start of the optimisation.

As the actual values of these parameters are printer- and/or material specific, they are kept as free variables in the optimisation environment where possible.





Material properties

The printing process has influence on the material properties of the resulting concrete artefact. From the concrete mix, which has to be compliant with the printer, to the depositing method, speed and direction a lot of printer specific parameters influence the material properties. In the "Optimising 3D concrete printing" project the following aspects are explored and tested:

- (An)Orthotropic behaviour
  The tests performed on the bulk material indicate that the mixture behaves in an orthotropic manner. This constant behaviour is incorporated in the optimisation.
- Non-linear behaviour of the mixture;
  Concrete-like materials do not behave elastic under loading. The cracked properties of the concrete are used in the optimisation.

Optimisation

Based on the material- and printer properties found, a custom topology algorithm has been developed. The topology optimisation algorithm strives to save material by iteratively filter the densities of the elements to obtain a structure that is as stiff as possible for a predefined fraction of the initial volume. By checking, during the iterations, that the geometry is printable and taking into account the material properties of the printed concrete during analysis, a structurally optimised, printable geometry is generated.

Results

The "Optimising 3D concrete printing" project has advanced the insight in the properties of both concrete 3D printers and the resulting 3D printed artifacts. Additionally, it has resulted in the first optimisation environment in which these capabilities and limitations are taken into account, enabling the use of additive manufacturing for the realisation of structurally sound, optimised concrete structures. As a proof of concept a topological optimised, concrete, printable floor slab is generated using the optimisation environment, and consequently 3D printed.

Delft University of Technology
BEMNext lab
dr.ir. **Jeroen Coenders**,
Maarten Mathot, **Pascal Martens**

Eindhoven University of Technology
dr.ir. **Freek Bos**, **Rob Wolfs** MSc.

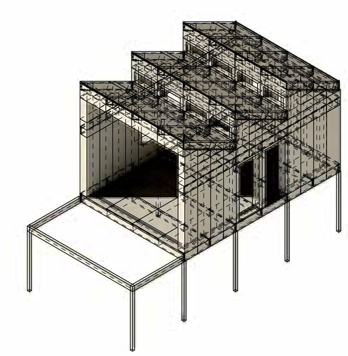
White Lioness technologies
ir. **Anke Rolvink**,
Puck Middelkoop MSc.,
dr.ir. **Jeroen Coenders**,
Maarten Mathot

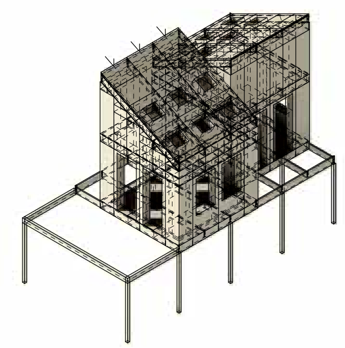
PD LAB

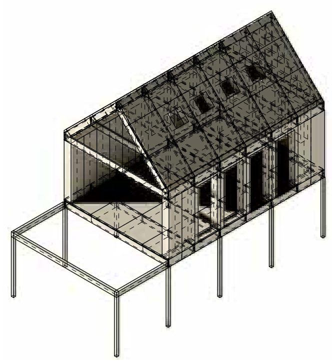
While architects and engineers work already entirely digitally to create our build environment, contractors and craftsmen on the building site still rely mostly on printed paper plans. This practice bears the risk of failure costs. With a growing demand for more sustainable and affordable housing it seems to be about time to start the digital revolution in this sector as well. With the help of computer controlled machines such as a CNC router we are able to fabricate building components based directly on the design of the architects. The digitally created files are sent to a router that cuts components out of wooden or natural fiberboards with high accuracy and speed. While all details that form a system of pre-engineered solutions will form a database of building blocks, costs will be lowered and quality increased. Within the Product Development Lab project the file to factory approach is investigated in form of the first fully digitally produced house as a demonstrator on the campus of the Faculty of Architecture. The project is embedded in the graduation education program, and offers a unique environment to explore the possibilities but also restrains of this approach.

Current Building Practice and Potential

Every building is unique, while most of the problems during erection seem to continue to repeat themselves. It is up to the craftsmen to solve problems on the fly. Some of the related costs are named failure costs. In the Netherlands, these failure costs in the building industry are an estimated 10,6% of its total turnover, resulting in annual costs of over 5 billion euro.







Imagine a building assembled from a well thought through kit of parts, like a kitchen from Ikea; with an infinite number of options available, the system used allows freedom to design within its system boundaries. Installations like light, water and gas or the placement of different third parties appliances are already taking into account and based on a highly industrialized production chain, meaning that the costs remain low and the task on site can be done with less effort.

File to Factory – Digital Fabrication – CNC Milling

Such mass-customization in design combined with the benefits of industrial production could become possible with digital fabrication. Emerging digitally driven construction processes like 3D printing and CNC milling create a direct link between digital and physical. This so-called file-to-factory process has the potential to bridge the gap between designing and making, as digital design information is directly used in construction to drive computer controlled machinery. While most of the productions in the automotive, marine and aerospace industries are already digitally designed and digitally produced with highly advanced fully automated production technologies, the quality of our buildings often still relies on the sharpness of the pencil point on the building site. Automation is the solution to our demands for individualism, comfort and human being. It allows for products with high precision, quality and at an affordable price.

Project Goals

Therefore, in this PD Lab project we do not use expensive technologies to make even more expensive architecture, but use the potential of these technologies to create high quality, low energy consumption affordable buildings that respond to our demanding challenge towards an energy neutral future. We would like to increase the quality of the building process and the building itself. The question is how this method or process can contribute to an economic and ecological advantage for the building sector. With this lighthouse project a platform will be developed to explore the applications of building sector related product development – the PD Lab.

Building System

Currently CNC milling already has great potential to create fully digitally produced building structures with integrated friction-fit connections, as shown in professor Larry Sass's (MIT) CNC house at MOMA and the open-source Wikihouse project. Pieter Stoutjesdijk developed this principle further with ECOnnect in Delft, using 600mm wide demountable integrated building components and making optimal use of the third axis on a CNC router to create 2.5D connections. Boards from agricultural waste and wood serve as the main building materials, therefore the structures roughly store their own weight in carbon emissions. Through the file-to-factory process, the components have the potential to be mass customized globally before being produced locally. The precision of the digital production process allows for fast and easy assembly and disassembly through integrated connections and airtight construction details. While the use of standardized building components accepts the reuse of the components like Lego blocks, the building itself allows a high amount of flexibility over time. Due to the use of environmental friendly materials the blocks themselves can be easily disassembled after its lifetime and fed back into the ecological cycle.

Conclusion

We take a pragmatic approach to architecture from an understanding of manufacturing and an appreciation of the way things go together. Up to now we have already concluded that the engineering part of such a system demands a high collaboration within all joining disciplines, communication on a digital platform or one common 3D model seems to be essential to allow the integration of all components. Scale tests and mock-ups to test fit and assembling orders become more and more essential; also as a base for discussion. In addition to the technological challenges a design methodology was set up as well to validate and judge requirements and demands. First iterations already showed that details and components will look differently if the requirements are set up differently.

The role of product design changes from delivering systems prior to the actual design and building process towards an integrated product building solutions. Here, the PD Lab itself is a case study and serves as a platform to explore new methods in product design. The project is supported by teaching activities at TUD.

Delft University of Technology
Dr.-Ing. **Marcel Bilow,**
Dr.–Ing. **Tillmann Klein,**
ir. **Pieter Stoutjesdijk**

Eindhoven University of Technology
prof.dr.ir. **Jos Lichtenberg**

ECOnnect

Fabrication Factory

Festool Group GmbH & Co

Guardian Glass

Isovlas Oisterwijk BV

Maasstad Hout & Plaat bv

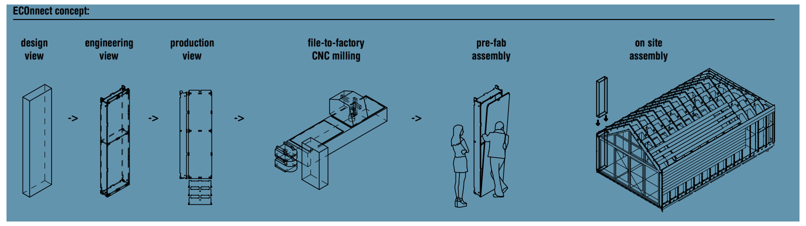
Reynobond Alcoa Architectural Products

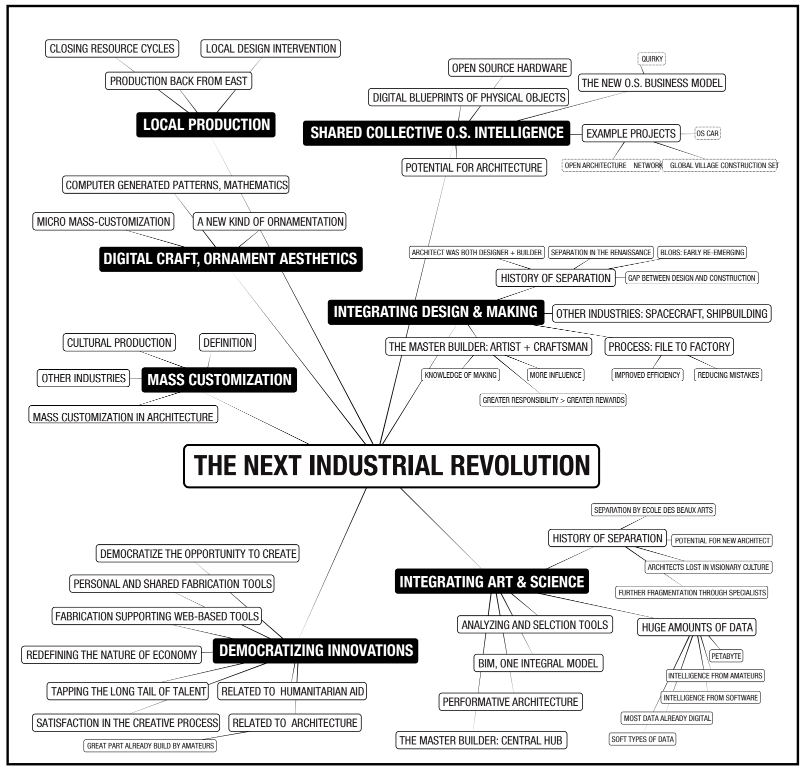
Poly-Ned

Rojo Steigers

Rollecate bv

The New Makers





POLYARCH

The challenge of the future is to minimize the energy consumption of buildings while maintaining an optimal comfort level in the interior. Controlling the energy streams into and out of the building and daylight management play an important role. Polymer technologies and especially responsive liquid crystal networks can improve the daylight management capabilities of building envelopes by making it adaptive on the Nano scale. A similar technology as used in this project is widely applied in LCD screens today but the integration into building technology poses many challenges.

In order to explore the possibilities of transferring polymer technologies into the field of building technology, an interdisciplinary research team has been established, covering the scientific areas of facades design and building physics on one side and chemical engineering on the other.

In a first step the PolyArch project focuses on applying reflective coatings on glass as a means of sun shading. Experiments and simulation show that adaptive coatings can have a clear energetic advantage when compared to current fixed metallic coatings. The project outlines the need for further research on technology development, colouration light perception studies, energy savings potential and other high potential applications.

The Building Envelope as a Potential Field of Application

Building envelopes need to deal with many, sometimes conflicting functions: Generally, a maximum of natural lighting is desired to reduce the need for energy for artificial lighting which in today's buildings accounts for approximately 30% of the total electricity demand. But daylight also contains a lot of energy that is sometimes unwanted and needs to be controlled.

For example, we need to block sun radiation in summer to prevent overheating, whereas in winter this incoming energy is desired to reduce the need for heating energy.

There are several traditional strategies to control daylight such as metallic coatings, exterior and interior sunshades. Existing daylight management strategies are rather inefficient or they involve considerable constructive effort, high investment costs and high maintenance and cleaning expenditures. On top of that the architectural impact of additional external or internal functional layers is big and they often do not comply with the designer's vision.

In this first approach, the project focuses on daylight management, but responsive polymer coatings also show a great potential for other building related applications such as responsive surfaces to control heat absorption/emission, responsive insulation and colour change of architectural surfaces.

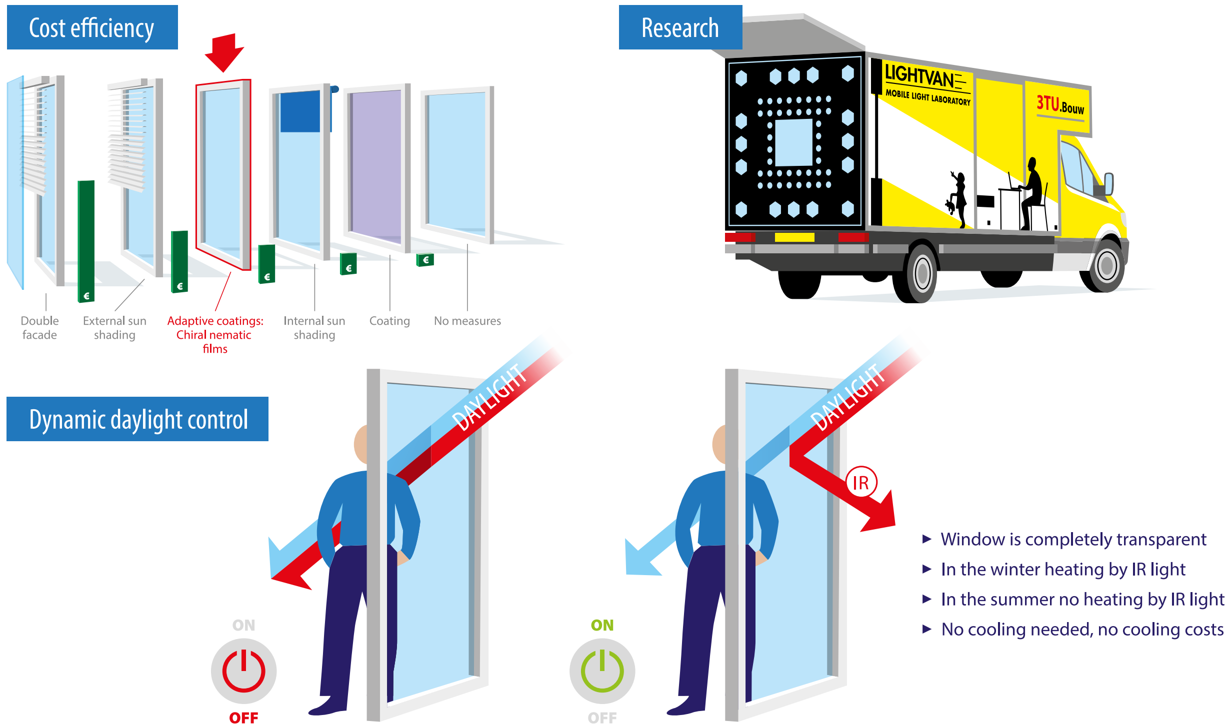
New Polymer Coating Technologies

Our collaborating party, the Department of Functional Organic Materials and Devices at the TU/e is a leader in developing new responsive coatings. These materials are able to switch physical properties such as colour, reflectance and heat transfer. For instance, so called 'responsive liquid crystal networks' may adapt the degree of reflection. The position of the reflection band in the electromagnetic spectrum can be dynamically shifted in response to temperature or light. Reflection can be shifted in the near infrared part of the spectrum, thus controlling heat flux without affecting transparency in the visible part of the spectrum. When applied on a glass window this film determines whether the heating part of sun light is being transmitted or reflected, thus offering a new and unique method to manage daylight in.

Potential Energetic Performance and Lighting Quality

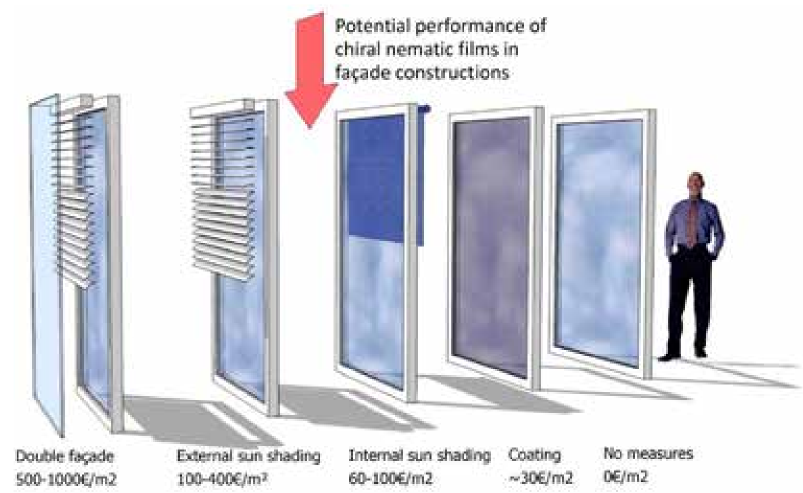
Due to the high intensity of sunlight in the wavelength range just outside the visible region, it is worthwhile to explore whether reflectivity of the switchable NIR coating in this range can be improved. A simulation study was carried out with idealized dynamic reflection properties in the range between 700 and 800 nm, to evaluate what the effect of such an improvement would be. The simulation results showed that for a south facing office zone in the climate of Madrid, an additional 15% of cooling energy reduction is possible compared to the existing window prototype.

The analysis of the samples' transmittances in the visible wavelength region has revealed that there is no negative impact on the interior illumination by daylight. At the same time, their spectral transmittance does not impact the quality of the light entering a building. Still it needs more research into perception studies because the film is light angle dependent which means that the colour disturbance could occur at different angles of sight.



Delft University of Technology
ir. **Eric van den Ham**, dr. **Truus Hordijk**, Dr.-Ing. **Tillmann Klein**

Eindhoven University of Technology
prof.dr.ir. **Jan Hensen**,
prof.Dr.-Ing. Habil. **Alexander Rosemann**
prof.dr. **Albert Schenning**,
dr. **Michael Debije**



Conclusion and Outlook

Up to now, the focus of the PolyArch project lies in applying reflective coatings on glass as a means of sun shading. A core feature of this technology is that the effect can be turned on and off. One can imagine a mirror that would switch to a transparent state. The switching determines if the sun radiation is transmitted into the room or reflected (in summer).

First samples have been created, measured and simulated for a coating in the infrared light spectrum, just outside the visible light. The human eye would thus not see the switching effect. It shows that the technology would reduce the cooling needs for south facing offices by about 15% as compared to existing static coatings. Theoretically the reflection could even be extended into the visible light range, displaying a sun-glass effect to prevent discomfort by glare and delivering a higher energetic effect.

Since the coating is responsive, this technology will potentially deliver a much better performance than current static metallic coatings.

Polymer coatings can be applied by embedding them into prefabricated insulated glass units. That means it can relatively easy be adopted into established design and building processes without the need for additional constructive effort for external sun shading devices. We can expect a high acceptance by decision-making parties.

But other applications need to be researched as well, such as opaque building envelopes that change colour according to architectural desires or absorbing and reflecting surfaces. 3TU.Bouw funding enabled a proof of concept for applying polymer technologies to the field of building construction and justifies the need for research into coloration light perception studies, energy savings potential, application possibilities and of course the development of switchable polymer coatings.

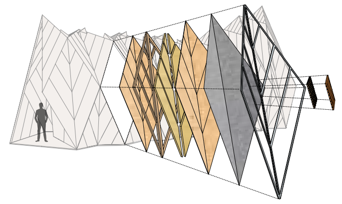
PUBLIC SPACE FOR REFUGEES

At this moment in history, a staggering 60 million refugees rely on international help - the highest number of displaced persons ever. A large variety of solutions have been developed that cater for primary needs. However, long-term public and community facilities have been neglected.

This project is addressing the necessity of dignifying community facilities in the context of permanent temporariness in refugee camps. Twelve plans for public buildings are developed, each with a different program. During the coming spring, certain parts of these projects will be built in scale 1:1, as part of the building exercises of the battalion of genie troops.

To develop these prototypes, a variety of camp types, public building types and techniques have been researched and analysed. All together these studies have been assembled in a catalogue, intended as a toolbox for designing public buildings for refugees.

At this moment in history, due to war and conflict, drought or flooding caused by climate change, we are confronted with over 60 million refugees - the highest number of displaced persons ever. To house displaced persons a large variety of solutions have been developed that cater primary needs. However, long-term public and community facilities have been neglected as an important mean of creating an environment of hope and dignity.

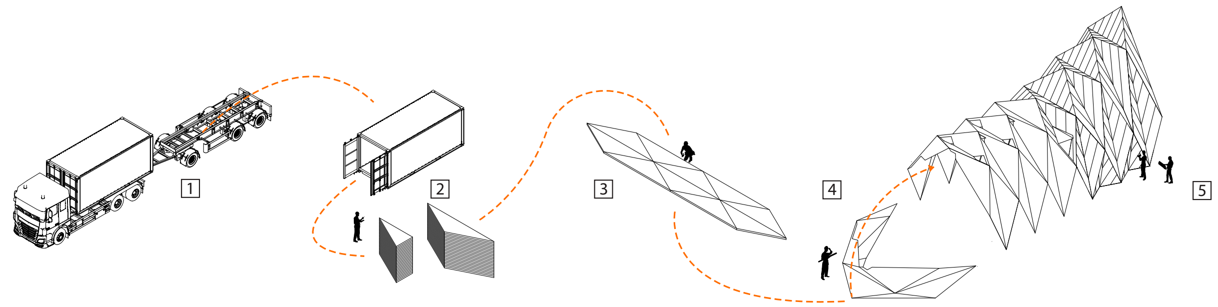


With the graduation studio "Public Buildings for Refugees" we aim to develop designs and prototypes of public buildings that can empower the life of displaced persons. Although refugee-camps are envisioned to provide short-term accommodation, the reality shows that people tend to stay there for years. The average stay in refugee camps has been estimated by UNHCR on 17 years. The permanency of these camps asks for long term solutions with not only housing but adequate community facilities, public space and public buildings to empower personal socio-economic development and enforcement of communities. Within this Lighthouse grant we will design solutions for these public buildings.

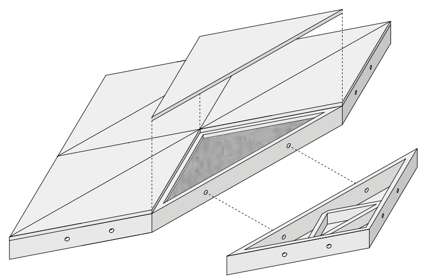
Currently, 12 plans for public buildings are being developed, each with a different program. During the coming spring, certain parts of these projects will be built in scale 1:1, as part of the building exercises of the battalion of genie troops. These will serve as prototype tests for the techniques and designs developed within this research.

In order to develop a prototype of a so-called "Public Building for refugees", a thorough research and analysis of existing camps of different kinds around the world has been done; a spectrum of architectural typologies of public buildings that could empower the life of the inhabitants in camps has been analysed and coinciding building methods and building technologies of varying form, from temporal to semi-permanent till permanent buildings have been studied. All together these studies have been assembled in a catalogue book. With the catalogue, we aim to give an overview and broader vision of different topics that are of relevance while designing public buildings for refugees.

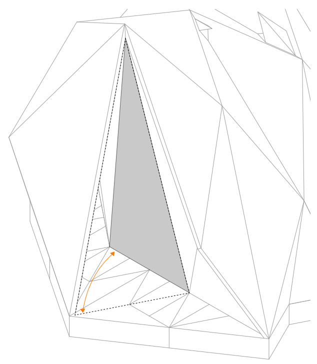
The ambition of the book is to frame a base point for a designer that is willing to dig into the issue of public buildings in refugee camps. More specifically, this catalogue breaks the topic in three parts: Urban, Building and Detail.



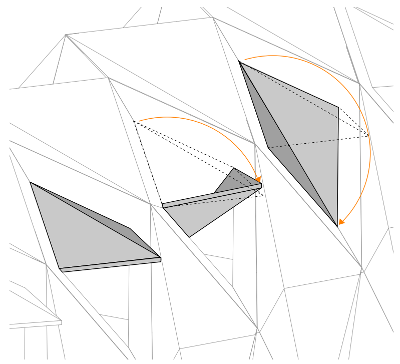
Building process



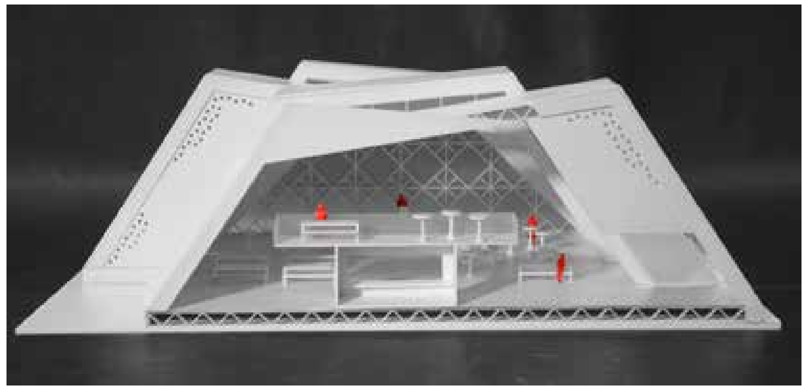
Connectable floor tiles



Door fragment



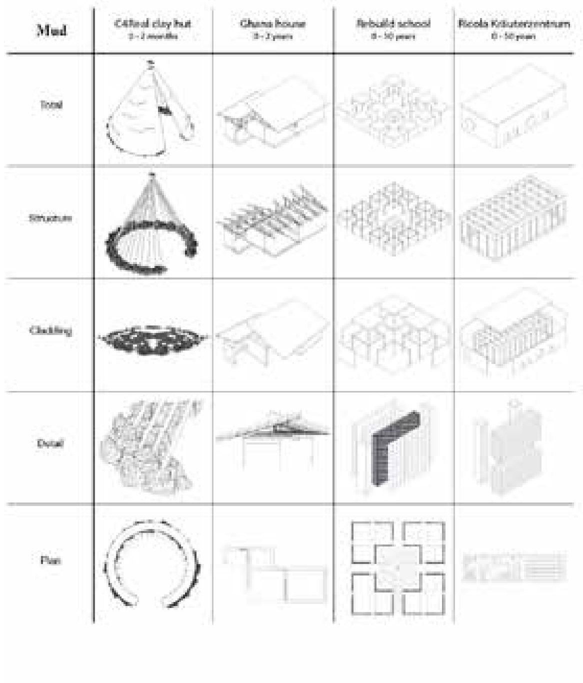
Window fragment

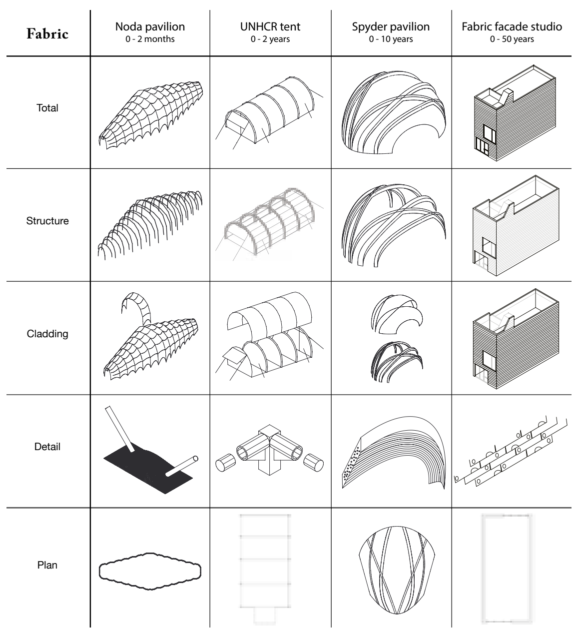


The Urban part provides an analysis of different camp typologies. Although other types of camps are included, the main focus is on refugee camps. More specific, the chapter offers insight in the structure of the camps and the way this typology has developed. The Building part provides information about different public buildings. The public functions discussed are health centres, community centres, schools, bus stops and market places. with the main focus on the influence of time on the specific typology. The detail part provides an overview of seven different building materials - earth, cardboard, bamboo, wood, fabric, metal, plastic - with the analysis of built examples in different time spans.

At this scale the aim is to clarify the properties and possibilities of each material in a range from temporal to permanent building.

Finally, the goal of the catalogue is to serve as a toolbox, from which a designer can grab elements when for instance designing a hospital. Then the detail part can be used to explore the possibilities of different materials.





Eindhoven University of Technology
prof.ir. **Juliette Bekkering,**
ir. **Sjef van Hoof,**
ir. **Kornelia Dimitrova,**
ir. **Eefje Hendriks**

Delft University of Technology
prof.ir. **Michiel Riedijk,**
Rick Krosenbrink

Koninklijke Landmacht
Commandant **Peter van Sorgen**

RE^3 GLASS

The applicability of glass in structures is continuously ascending, as the transparency and high compressive strength of the material render it the optimum choice for realizing diaphanous structural components that allow for light transmittance and space continuity. The fabrication boundaries of the material are constantly stretching: visible metal connections are minimized and glass surfaces are maximized, resulting to pure all-glass structures. Still, due to the prevalence of the float glass industry, all-glass structures are currently confined to the limited forms and shapes that can be generated by planar, 2D glass elements. Moreover, despite the fact that glass is fully recyclable, most of the glass currently employed in buildings is neither reused nor recycled due to its perplexed disassembly and its contamination from coatings and adhesives.

Cast glass can be the answer to the above restraints, as it can escape the design limitations generated from the 2-dimensional nature of float glass. By pouring molten glass into moulds, solid 3-dimensional glass components can be attained of considerably larger cross-sections and of virtually any shape. These monolithic glass objects can form repetitive units for large all glass-structures that do not buckle due to slender proportions and thus can take full advantage of the stated compressive strength of glass. Such components can be accordingly shaped to interlock towards easily assembled structures that do not require the use of adhesives for further bonding. In addition, cast glass units–due to their increased cross section– can tolerate a higher degree of impurities and thus can be produced by using waste glass as a raw source.

Grasping this potential, the "Re^3 Glass" project aims to develop a methodology and guideline for the sustainable application of structural glass in buildings in respect to the waste hierarchy of Reduce, Reuse and Recycle. In specific, a threefold Re3 approach is suggested:

Step 1. REcycle by Employing Waste Glass

Although in theory glass can be endlessly remelted without loss in quality, in practice only a small percentage gets recycled, mainly by the float and packaging industry. Most of the discarded glass fails to pass the high quality standards of the prevailing glass industry - due to coatings, adhesives, other contaminants or incompatibility of the recipe - and ends up in the landfill. However, employing discarded glass in cast components for building applications can be a way to reintroduce this waste to the supply chain. This is because such components can tolerate a higher percentage of inclusions, without necessarily compromising their mechanical or aesthetical properties.

Step 2. REduce by Implementing Smart Geometry

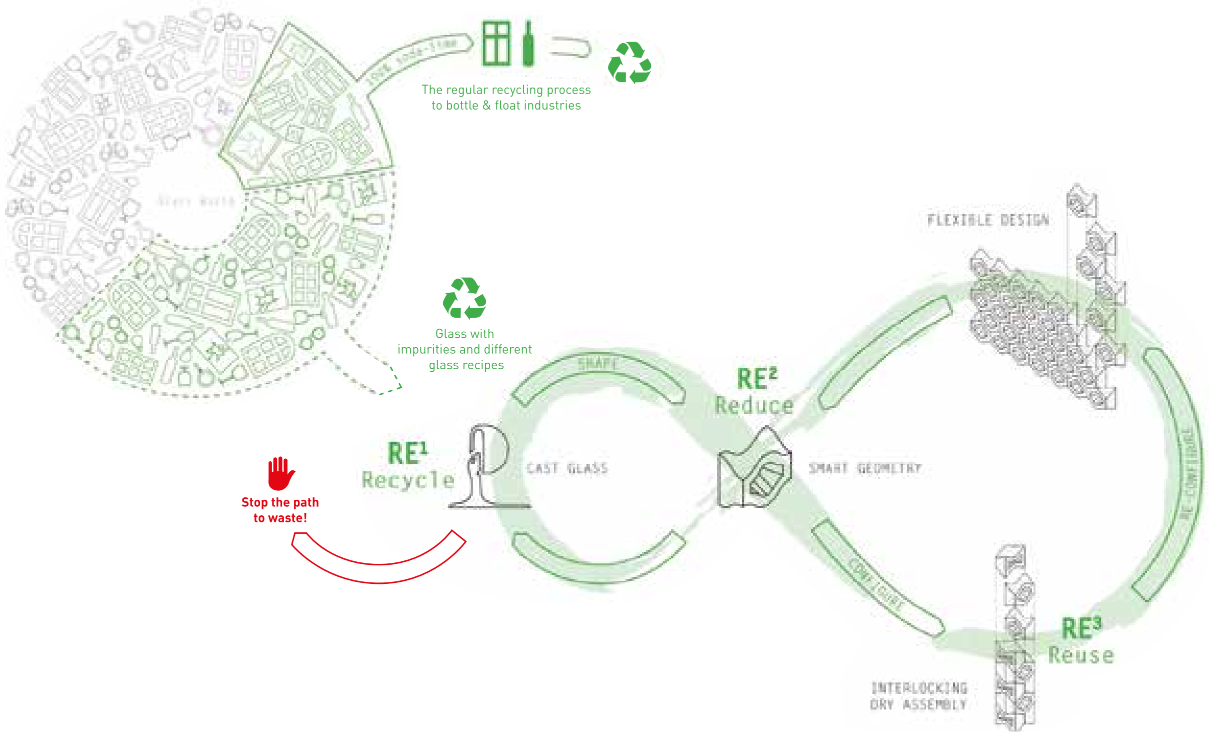
The use of cast glass is proposed instead of the commonly applied laminated float glass, to achieve solid monomaterial components of the desired cross section and form. Owing to their large cross-sectional area and monolithic nature, cast glass components besides having an unlimited freedom in shapes, can form repetitive units for the generation of 3-dimensional, self-supporting glass facades and walls, sparing the necessity of an additional supporting structure. Smart geometry implemented in the form of cavities and notches leads to lightweight yet strong components, reducing not only the required raw material but also the overall embodied energy.

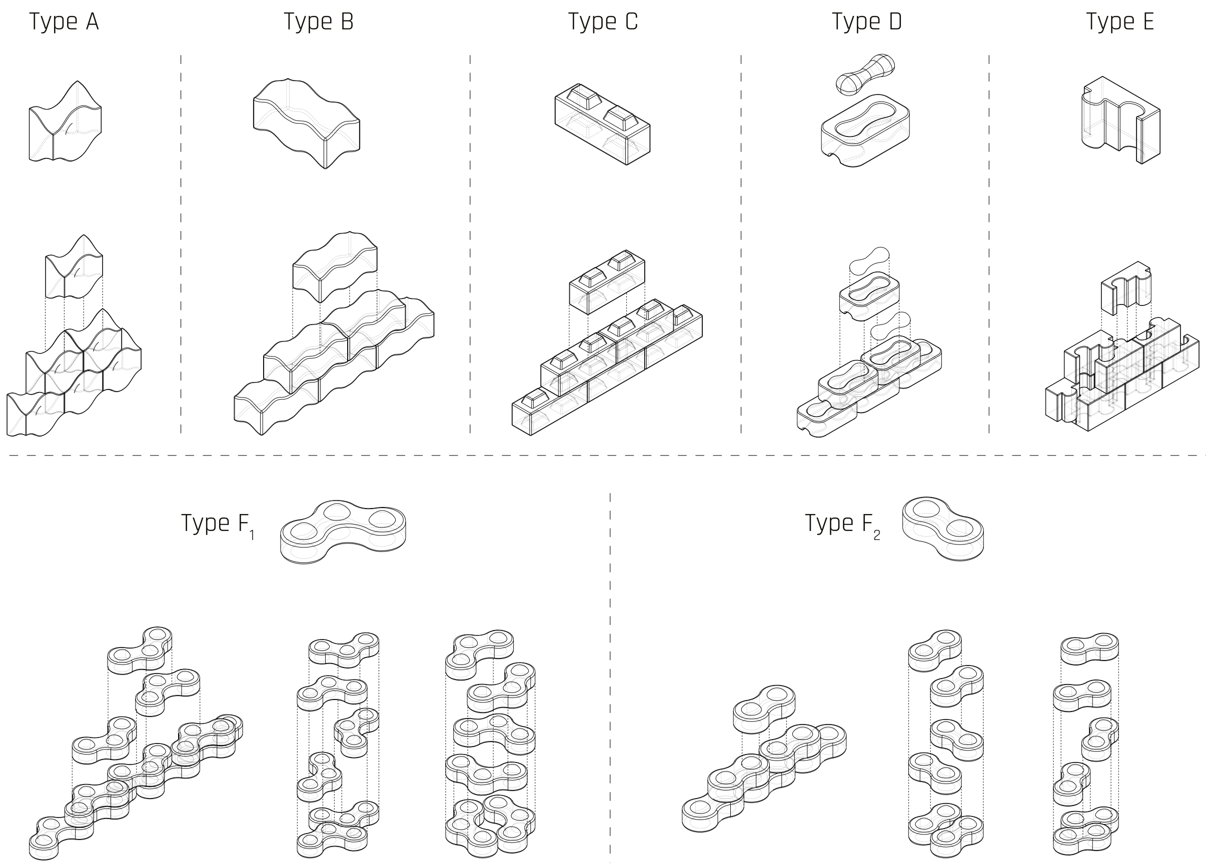
Step 3. REuse by Designing Interlocking Components

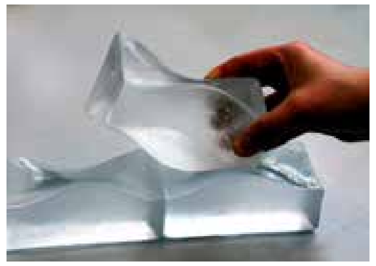
Currently, the few realized structures using cast glass components employ either a steel substructure or an adhesive of high bonding strength, typically less than 2 mm thick, to ensure the rigidity and lateral stability of the construction. Whereas the first solution compromises the overall level of transparency, the second results to a permanent construction of intensive and meticulous labour and extreme accuracy requirements. In this research the potential of a novel, reversible glass system comprising dry-assembly, interlocking cast glass components is explored. Owing to its interlocking geometry, the proposed system can attain the desired stiffness and stability with the aid of minimal metal framing. Furthermore, the suggested system circumvents the use of adhesives by using a dry, colourless interlayer as an intermediate between the glass units. Besides preventing stress concentrations due to glass to glass contact, the dry interlayer can also accommodate the inevitable dimensional tolerances in the cast units' size. Most important, the dry-assembly design allows for the circular use of the glass components, as they can be eventually retrieved intact and reused.

Proof of Concept

To validate the concept, different component geometries are developed and assessed in terms of mechanical interlocking capacity, mass distribution and ease of fabrication. Numerical models are made to predict the most sensitive areas in the brick designs. In parallel, research is conducted on different materials and production methods for the dry, transparent interlayer. As a proof of concept, the most promising interlocking forms are kilncast in 1:2 scale. The components are then dry-assembled in series of three and structurally tested under shear, to demonstrate the feasibility of the system.







Simultaneously, the potential but also the limitations of recycling glass in order to obtain load-bearing components are assessed. In this direction, an overview is provided regarding the types of glass that reach the recycling plants and the types that do not, arguing on the reasons behind this selection. A series of experiments questions the possibility of recycling everyday glass waste, from beer bottles and Pyrex® trays to mobile phone screens. Each type of glass waste is initially cast separately to define the flow capability at a temperature range between 900C-1100C, the risk of crystallisation, and the alterations in colour due to oxidation and reduction. Flux agents are added to samples of high viscosity at the aforementioned temperature range to facilitate the flow and reduce the required energy for recycling. Then, the possibility to mix different glass recipes at temperatures between 900C-1450°C without cracking during the cooling and annealing cycle is evaluated. Aim of this research step is to achieve homogeneity in the glass components and good physical and mechanical properties despite the initial incompatibility of the mixed glass types.

Outcome of the "Re³ Glass" project is the new generation of REcyclable, REducible and REusable cast glass components, which suggests an innovative and sustainable way of building with glass.

Delft University of Technology
ir. **Telesilla Bristogianni**,
ir. **Faidra Oikonomopoulou**,
ir. **Lida Barou**, dr.ir. **Fred Veer**,
prof.ir. **Rob Nijsse**, ir. **Erwin Jacobs**,
Giulia Frigo

University of Twente
dr. **Elma Durmisevic**,
ir. **Pieter Beurskens**

Southern Illinois University, School of Art and Design
prof. **Jiyong Lee**, **Katherine Rutecki**

REPRINTING ARCHITECTURAL HERITAGE

Additive Manufacturing (commonly known as 3D printing) technology has become a global phenomenon. In the domain of heritage, 3D printing is seen as a time and cost efficient method for restoring vulnerable architectural structures. The technology can also provide an opportunity to reproduce missing or destroyed cultural heritage, in the cases of conflicts or environmental threats. This project takes the Hippolytuskerk in the Dutch village of Middelstum, as a case study to explore the limits of the existing technology, and the challenges of 3D printing of cultural heritage. Architectural historians, modelling experts, and industrial scientists from the universities of Delft and Eindhoven have engaged with diverse aspects of 3D printing, to reproduce a selected part of the 15th century church. This experimental project has tested available technologies to reproduce a mural on a section of one of the church's vault with maximum possible fidelity to material, colors and local microstructures. The project shows challenges and opportunities of today's technology for 3D printing in heritage, varying from the incapability of the scanning technology to capture the existing cracks in the required resolution, to the high costs of speciality printing, and the limited possibilities for combining both printing techniques for such a complex structure.

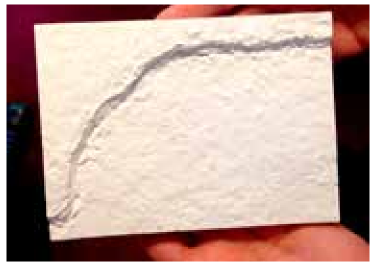
Connecting new technological developments in 3D scanning and 3D printing with cutting-edge research in the humanities and architectural design, the project aims at developing material reproductions of architectural heritage, to engage in research on the potential of 3D printing technology for heritage studies, and to explore the challenges and potential developments to the technology for both heritage professionals and affected communities. Careful historical study of available archival documents and earlier restorations helped us decide on a selection of the study object, a painting of an angel, riding a lamb, located in a vault near the choir. The painting depicts the last judgement, and is part of series of scenes made by Albrecht Dürer.

Throughout the process of scanning and printing the section, we encountered multiple challenges, varying from the incapability of the scanning technology to capture the existing cracks in the required resolution, to the high costs of speciality printing with particular materials, and the limited possibilities for combining both printing techniques for such a complex structure. Additional fundamental challenges have emerged from the decision-making process, with regards to issues of copying and replication, scale, presentation, and access to information.

Use of 3D scanning technology in the church's vault shows the multitude of challenges of such projects in the heritage field. Available 3D scans for the church, taken at ground level, lacked the level of detail we needed, requiring new scanning. As it was practically impossible to reach the required height with the scaffolds, the project members took color pictures and made the required scans with the laser scanner from as close as possible, with a resolution of around 0.5 mm and with the highest quality available.

Translating the 3D scans into usable data had its own difficulties. Combining photogrammetry with laser scanning, we developed 3D virtual models, and then selected a piece of about 15×20 cm for 3D printing trial. We selected the particular piece for scanning and printing, as it has little curvature (making the application easier for 3D printing of a colored surface), but included the crack (so that we could test the challenge of scanning and printing). Despite the high resolution, the depth of the structural crack did not appear clearly in the scan.

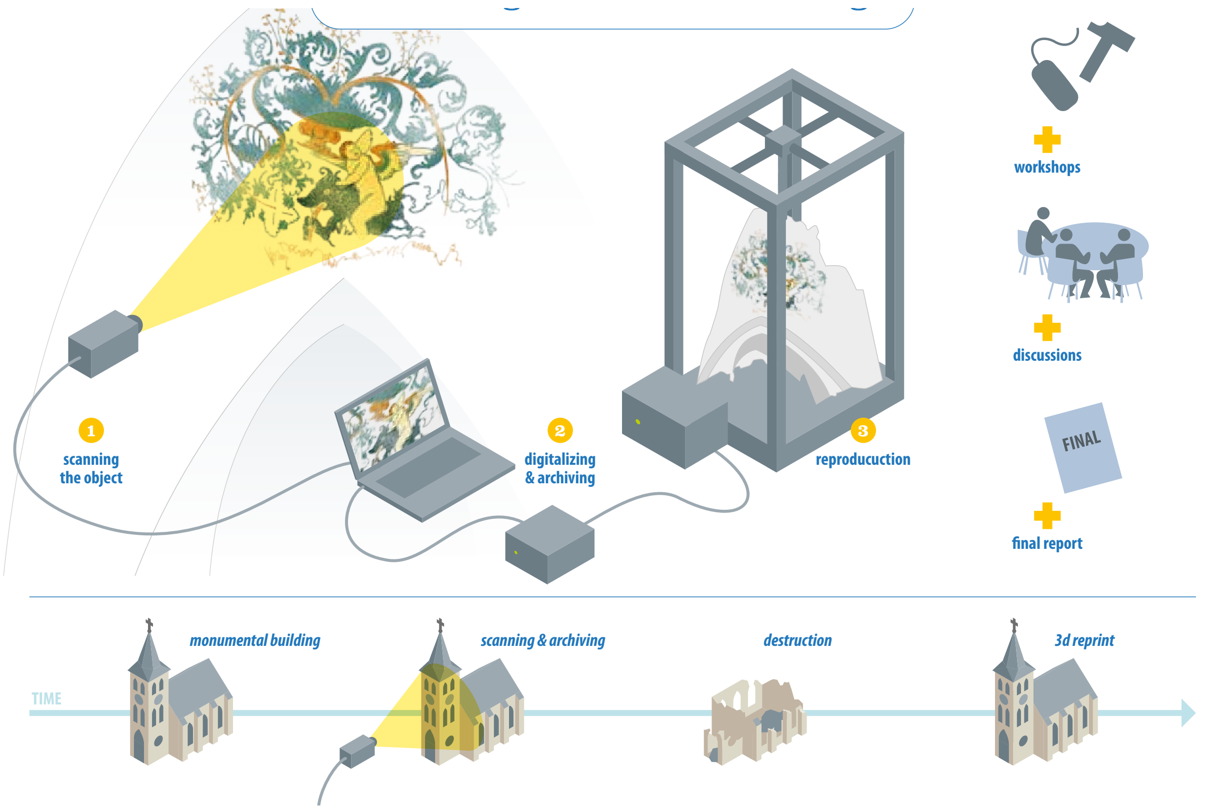
In the absence of printing technology that can apply a color to a non-flat surface, we decided to explore the opportunities of printing the painting on a thin film and applying it over a 3D printed structure with visible surface microstructures. In principle, the film print ought to take into account the deformation based on surface unevenness and curvature. While it is in principle possible to generate a computer model deformation (UV Mapping?), we decided to ignore this aspect for our pilot project.



Having separated the structural printing and that of the film, we opted to first experiment with materials for 3D structural (non-colored) 3D printing. The CAMlab of TU Delft produced a first gypsum test print without color, providing a good first impression of the surface structure. We found that the thin lines produced by the gypsum print technology were insufficient to render the texture of a wall surface. Additional test prints were produced by QUBICX, to experiment with different materials. This included: once coloured sandstone produced on the 3D systems ProJet660Pro, and one PA12 white (nylon) produced on a EOSint P770 SLS.

Both of these objects had the qualities necessary to serve as sub structure. To reduce the cost of printing material, we decided to hollow out the piece and to apply spider-like/honey-comb back structure. Using such a structure in the back would also hollow to use the process in architectural heritage to fill e.g. holes, or missing parts as an alternative to Styrofoam.

For the front structure, we discussed several options. Following on conversations with specialists and companies we had to accept that the inkjet option, which has been used in the reproduction of Rembrandt paintings was not possible for this project. Current technology can only print on flat surfaces and not the complex vault structure of the church, which includes cracks and a complex topography. Colored, structural 3D printing technology would give the object a "plastic" look, as the technology does not provide an inkjet quality yet. We therefore opted to



print the final colors and textures on a thin flexible foil layer (50 microns) and fix it over the solid 3D structure, which in this case will have all the microstructures, and grains. Reducing the glossiness of the material as much as possible, so the final product can be similar to the church mural remains a challenge that we are trying to address through an additional matt layer.

To test the implications of this technology for architectural design, two educators have collaborated with students to complement the technological challenges. Given that contemporary printers can only produce tiles of a maximum size of YYY and YYY, Peter Koorstra (TU Delft) challenged students in the Form and Modelling design studio to understand the seam between these tiles as pattern. Juliette Bekkering and Barbara Kuit (TU Eindhoven) added yet another aspect to the research, through investigating the possibilities to reproduce the columns using concrete 3D printer.

The goal of the project, to be presented in March 2018 is a scaled 3D print of the entire scanned area with applied file. In the run-up to this event, a workshop entitled "Re-Printing Architectural Heritage" will bring together scholars from various fields to discuss the first outcomes of our research on the Hippolytus church and of a parallel project involving the Mauritshuis.

Delft University of Technology
prof.dr.ir. **Carola Hein**,
dr. **Michela Turrin**, prof.dr.ir. **Joris Dik**,
John Hanna, **Miktha Alkadri**,
Serdar Asut,
prof.Dr.-Ing **Ulrich Knaack**,
Peter Koorstra

Eindhoven University of Technology
prof.ir. **Juliette Bekkering**,
ir. **Barbara Kuit**

Culrural Heritage Agency of the Netherlands
Albert Reinstra

National Archives
Angela Dellebeke

3D idea printing
Dave Vanhove

QUBICX
Dick Vlasblom

Foundation for Old Groningen Churches
Jur Bekooy

BLOMSMA PRINT&SIGN
Ron Teeuw

4Visualization
Valentin Vanhecke

3M Netherlands
Wim Oostveen

RESTORATIVE GLASS

The application of structural glass as the principal material in restoration and conservation practices is a distinguishable, yet discreet approach. The transparency of glass allows the simultaneous perception of the monument at both its original and present condition, preserving its historical and aesthetical integrity. Concurrently, the material's unique mechanical properties enable the structural consolidation of the monument. As a proof of concept, the restoration of Lichtenberg Castle is proposed. Solid cast glass units are suggested to complete the missing parts, in respect to the existing construction technique and aesthetics of the original masonry. Aiming for a reversible system, the glass units are interlocking, ensuring the overall stability without necessitating permanent, adhesive connections. This results in an elegant and reversible intervention.

This research investigates the potential of structural glass as a principal material in restoration and conservation practices in order to highlight and safeguard our built heritage; a distinguishable, yet discreet approach. Current restoration treatments with traditional materials bear the risk of conjecture between original and new elements, while the ambition to enhance the structural integrity of the endangered structures, often results in visually invasive and irreversible solutions that can impair the authentic image of the monuments. In this context, glass could be the answer to this on-going debate between restoring and preserving, a promising restoration solution able, on the one hand to consolidate the historic buildings and on the other hand to reveal their stratification. The transparency of glass enables the simultaneous perception of both the original and ruinous state of the monument, giving a material and immaterial appearance that relates the structure to both the past and the present setting. But equally important, owing to the mechanical properties of glass, the glass addition can contribute to the structural preservation of the monument.

As a case study, the restoration of the Lichtenberg Tower in Maastricht is proposed. The Lichtenberg Tower - the oldest castle ruin in the Netherlands - has undergone numerous phases of destruction, decay, rebuilding and renovation during eight centuries. The scars of time and human intervention are evident in the monument's brickwork which forms a beautiful collage of different materials and building rhythms. Last century's reinforcement and preservation acts, however, burdened the monument with a prevailing steel structure- alien to its nature.

In this proposal, all foreign elements such as steel anchors, rods, and staircases, as well as the contemporary brickwork, are removed in favour of glass components that fill the missing parts and prevent the monuments' walls from drifting apart and collapsing. The innovative contribution of this glass restoration approach, besides allowing for a transparent addition, lies in the development of a completely reversible system, complying with the conservation guidelines suggested by the Venice Charter. To avoid any permanent bonding between the existing structure and the glass intervention, dry connections are proposed between the glass and the historic matter. Solid cast glass units are suggested, in respect to the existing construction technique and aesthetics of the original limestone masonry, to reinforce the monument by replacing the missing parts. To ensure the overall stability of the façade, the cast glass units follow an interlocking geometry, sparing the necessity of permanent, adhesive connections. The high stiffness and compressive strength of glass result in a lightweight glass wall of minimal thickness that ensures the desired structural consolidation without burdening the monument.

Different interlocking systems were explored to conclude to the optimum shape. As a proof of concept, the interlocking units are cast in the TU Delft Glass Lab, resulting to a 1:2 scale prototype. The aesthetic value of this solid cast glass interlocking masonry is articulated with glass elements resembling the original stone texture, while at the same time allowing for the perception of the surroundings. Three different sizes of bricks are designed to follow the gradient of different masonry styles, as this has been formed over the centuries. To evaluate the degree of cooperation of the units, testing in shear has been performed, manifesting the potential of the dry-assembly system as a compatible and elegant design approach for the preservation of our heritage. For the safe dry-assembly of the glass bricks, a transparent PET interlayer is proposed, specially thermoformed to match the interlocking surface.

Glass casting process at the Glass&Transparency Lab of TU Delft by the flowerpot method.

The autoclave used at the Glass & Transparency Lab for casting the glass components

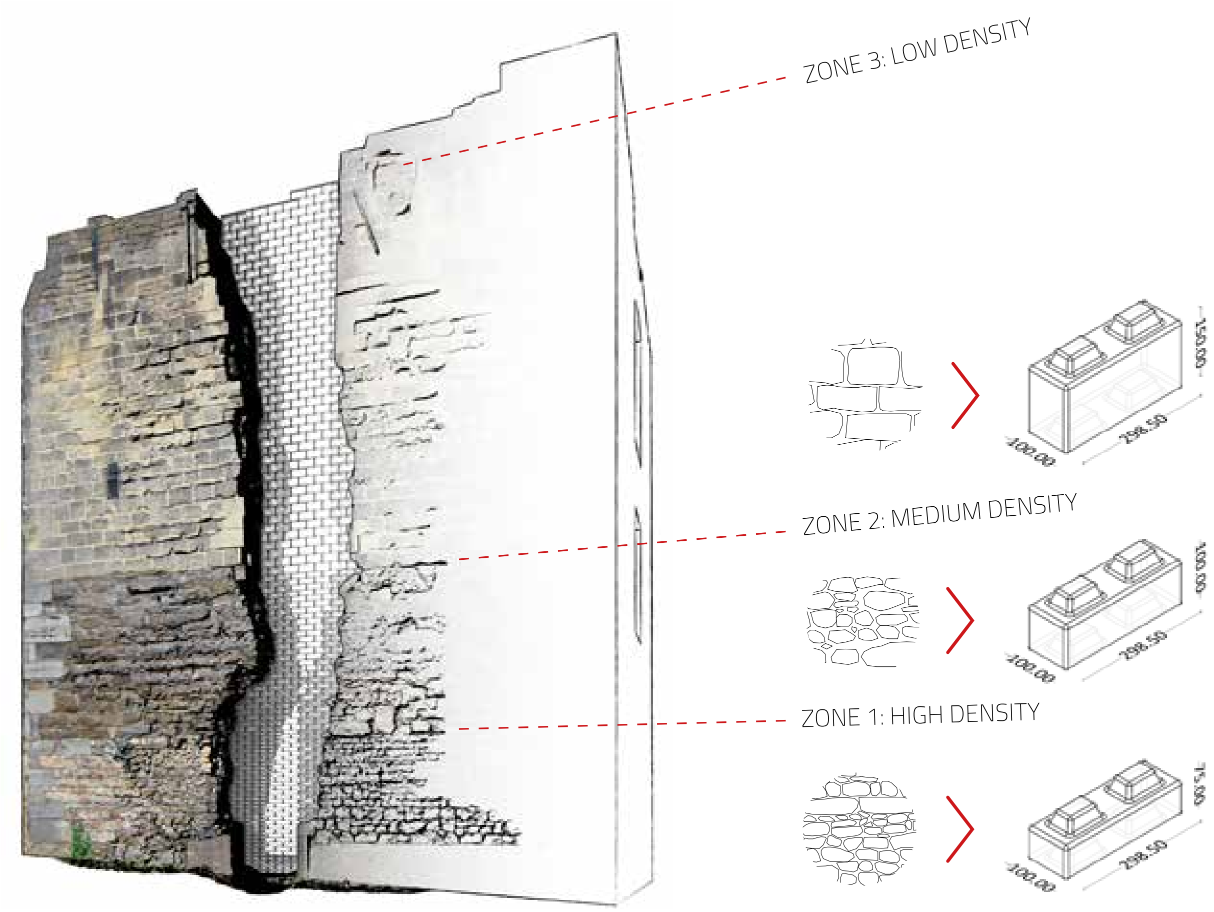
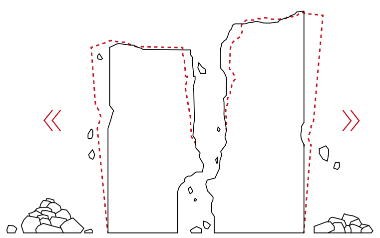
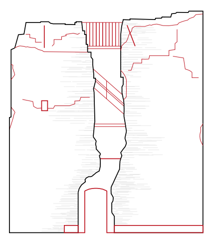


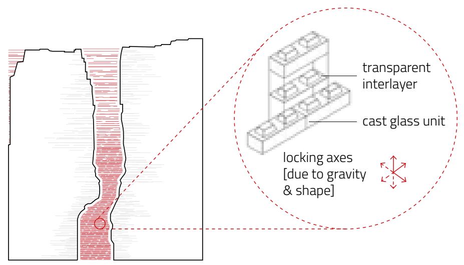
Illustration of the proposed glass restoration in Lichtenberg Castle, Maastricht.



PROBLEM
Monument under threat of total collapse



CURRENT SOLUTION
Visually intrusive treatments



PROPOSED TRANSPARENT SOLUTION
Structural consolidation using cast glass

The connection between the glass masonry system and the historic wall is also designed to be discreet and reversible and any use of adhesives is prevented. Various scenarios were evaluated and tested in full scale prototypes, concluding to the proposal of a connective element that matches the exact shape of the wall on one side, and the interlocking geometry of the glass bricks on the other. Steel rods are anchored at key locations along the cracked historic wall to fix the special connective elements. The crack of the monument is 3D-scanned by a FARO® Focus phase difference laser scanner and the obtained pointcloud is converted to a 3D model. Based on this accurate 3D model, the connectors are developed. The connective components are proposed to be 3D-printed in plastic or 3D-milled in wood, to achieve accuracy, but more research is to be conducted to determine the most optimum material choice.

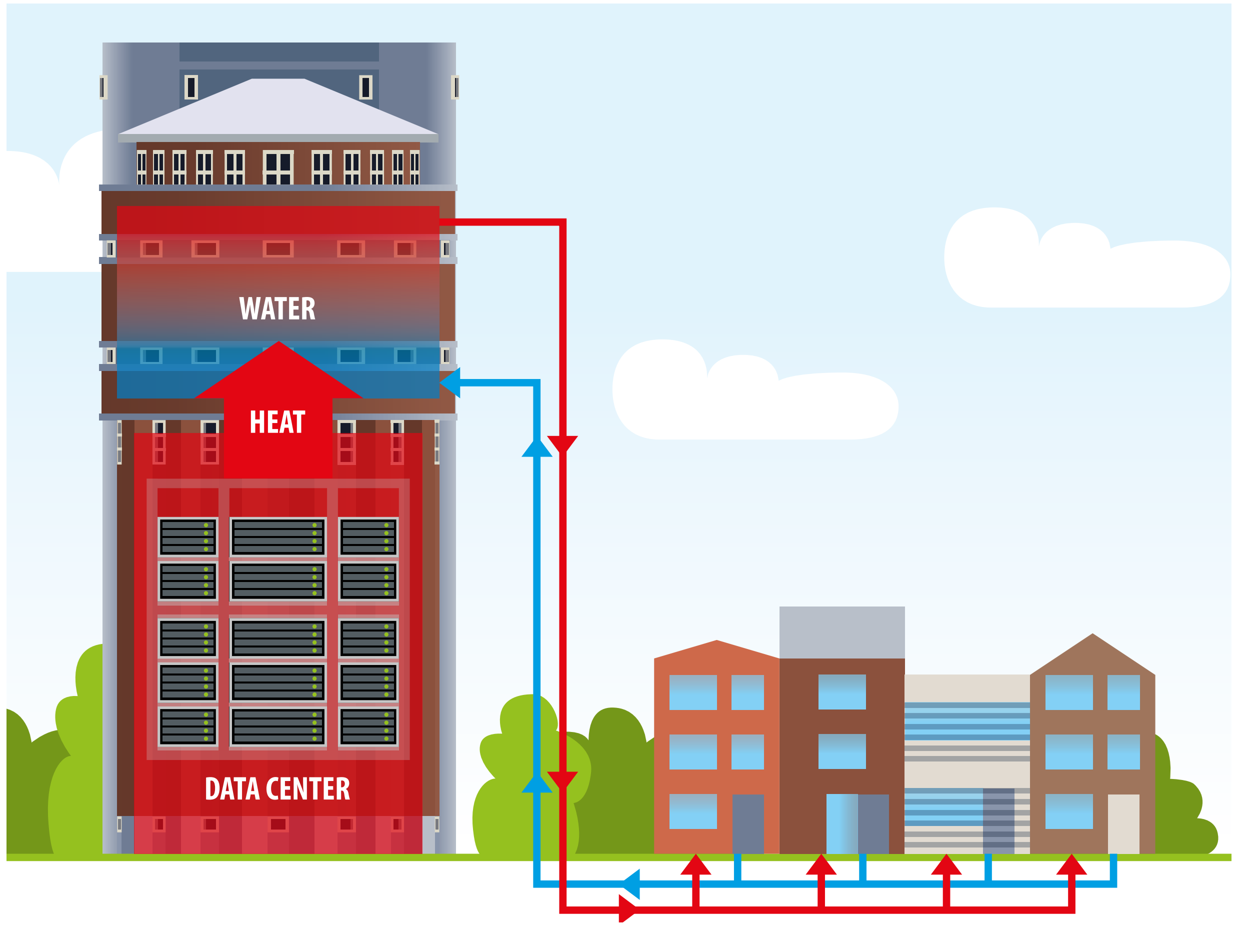
Regarding the interior of the monument, an all-glass ascending path to the top of the tower is created using float glass components. The transparent staircases and floors result to the least intrusive visual impact. The overall approach respects the rich history of the monument and highlights it, in a discreet transparent manner.

Delft University of Technology
ir. **Faidra Oikonomopoulou**,
ir. **Telesilla Bristogianni**, ir. **Lida Barou**,
prof.ir. **Rob van Hees**,
prof.ir. **Rob Nijsse**, dr.ir. **Fred Veer**

Eindhoven University of Technology
dr.ir. **Henk Schellen**,
dr.ir. **Jos van Schijndel**

ABT

POESIA



DE REUS VAN SCHIMMERT

The water tower of Schimmert was built in 1926 to cover the needs of water of not only Schimmert but of the surrounding area as well. This imposing 38 meters high tower dwarfs any nearby buildings, providing a 360o view of the surrounding area and deserves its pseudonym de Reus van Schimmert (the Giant of Schimmert).

In the attempt to find a sustainable business model for the iconic building the concept of installing a data center in its core is investigated. The waste heat from the servers will be transferred to the reservoir on the top and from there used to power a district heating system in Schimmert.

The cloud, mobile services, Big Data, Internet of Things and social media have become important services in today's digitalized society. And data centers are what enables them. The need for IT infrastructure is ever increasing and their operation is critical. Although the data center business is booming, the growing demand of these services not only directly translates to higher energy demand and operating costs but also leads to a more severe impact on the environment.

However, within these very same data centers lies the potential to address such environmental, economic and societal concerns. Data centers are uniquely positioned at the crossroads of both energy and data networks and will have the opportunity to become key players within their local sustainable energy systems.

Eindhoven University of Technology
Konstantinos Tzanakakis,
dr. **Madeleine Gibescu,**
prof.dr. **Ed Nijssen**

De Reus van Schimmert
Nico Eurelings

Heat Disposal

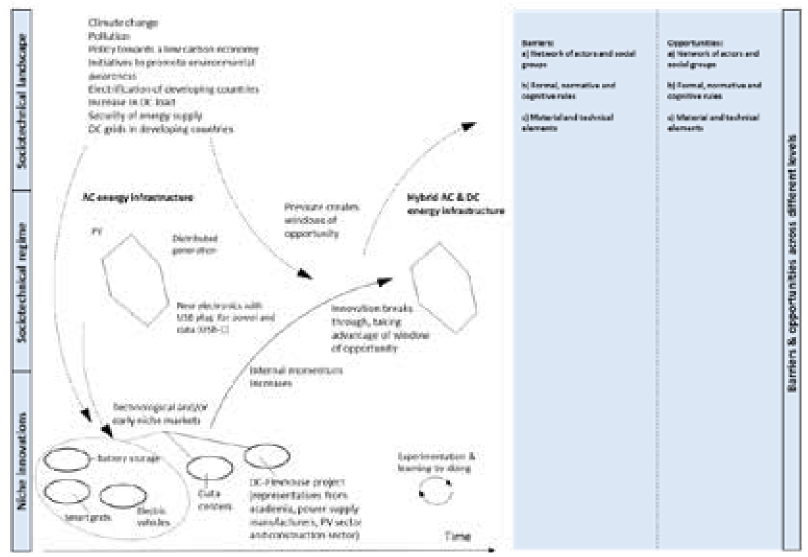
The IT equipment generates heat throughout its operation. Actually, 100% of the electricity fed to a server is transformed into heat and this heat needs to be removed from the server rooms. For this reason, data centers need cooling to maintain environmental conditions suitable for the operation of the information technology equipment. Heat disposal is of paramount concern in the design of data centers. Typically, the heat is dissipated away from the IT equipment and practically wasted into the atmosphere. However, this waste heat can be re-used for many applications, providing an extra source of revenue to the data center operator while at the same time improving the energy efficiency of the facilities. This has as a result a smaller CO2 footprint and a reduced cost of ownership.

De Reus van Schimmert has the potential to be transformed into a data center that smartly utilizes the waste heat that is generated by the IT operation. The proposed design, consisting of the data center and the corresponding district heating system fueled by the data center's waste heat, is a venture that can position itself strategically in the local growing ICT market. In addition to that, selling the waste heat provides an additional income source while providing once more a service to the citizens of Schimmert.

Sixty-five houses can be heated using the waste heat. However, a difference exists between the time the waste heat is available from the IT operation and the actual demand in the houses. Storage technology has the potential to give a solution to the challenge of this mismatch, providing security of supply without the need of oversizing the system to guarantee a continuous energy flow. For this reason, the reservoir on the top of the tower will be used as a buffer, a heat storage system. During times of low demand the excess heat is stored in the tank while when the demand surpasses the supply, the difference is covered by the stored energy.

Sustainable Paradigm

Data centers are likely to remain an important part of the global economy for many years to come. At present the demand for such facilities is increasing and, as users find more ways to enjoy and exploit access to vast amounts of data, the demand will increase even further. De Reus van Schimmert can be once again a lighting beacon of the area, this time because of its sustainable paradigm. It can showcase that although data centers demand massive amounts of electricity and consequently are responsible for CO2 emissions, they can put this energy in good use by providing sustainable heating to the local area.



RFID SENSORS

This project set out to prove that Radio Frequency Identification (RFID) sensors can be used to monitor, to begin with, compaction temperature and pressure during the asphalt construction process and afterwards during a typical life cycle of the paved asphalt layer. Several RFID sensor manufacturers have suggested that the technology is robust enough to be applied in the rather harsh asphalt construction environment. If it is and if sensors become small enough ("smart dust"), it will become possible to store all relevant composition, construction and performance data on sensors in the asphalt. It would revolutionize pavement management by having the information available "on the spot". By having car sensor data linked to pavement locations and sensors, a smart road that actually signals when repairs are needed becomes feasible.

The aim of this LightHouse project was to see if the sensors are indeed robust and small enough and to find out if they could be used in practical applications. We started by firstly finding temperature and pressure sensors that could withstand the high asphalt mix temperatures and heavy pressures of roller compactors and the resulting shear stresses between aggregates. The sensors were then to be tested in two laboratory and two site testing phases.

Finding Appropriate Sensors

Asphalt construction is an intensive process where sensors will have to survive high asphalt temperatures and compaction pressures during paving and compaction.

RFID temperature sensor placed in the G.J. Van Heekstraat, Enschede

A desk study and initial contact with several RFID manufacturers highlighted a first challenge. While several RFID temperature sensors were found to be suitable for possible use in asphalt applications, few suitable pressure sensors were found. A choice was therefore made to test passive RFID temperature sensors given that they are wireless, make use of an external energy supply (reader) and are relatively inexpensive when compared to active sensors.

Sensor Placement in Asphalt Layers

A huge challenge turned out to be the placement of the sensors in the asphalt layer so that it remains stable during measurements. Anchoring was trailed in asphalt slabs including fixing it to plates, testing mastic asphalt mounting blocks and using bitumen strips. Anchoring success was measured against displacement, tilt, compaction and pressure against the sensor. The placements were tested using a gyrator and a hand-held roller compactor. A multi-criteria analysis showed the mastic asphalt blocks and bitumen strips to be most suitable for mounting the sensor in the asphalt layer.

Pilot Installation on Site

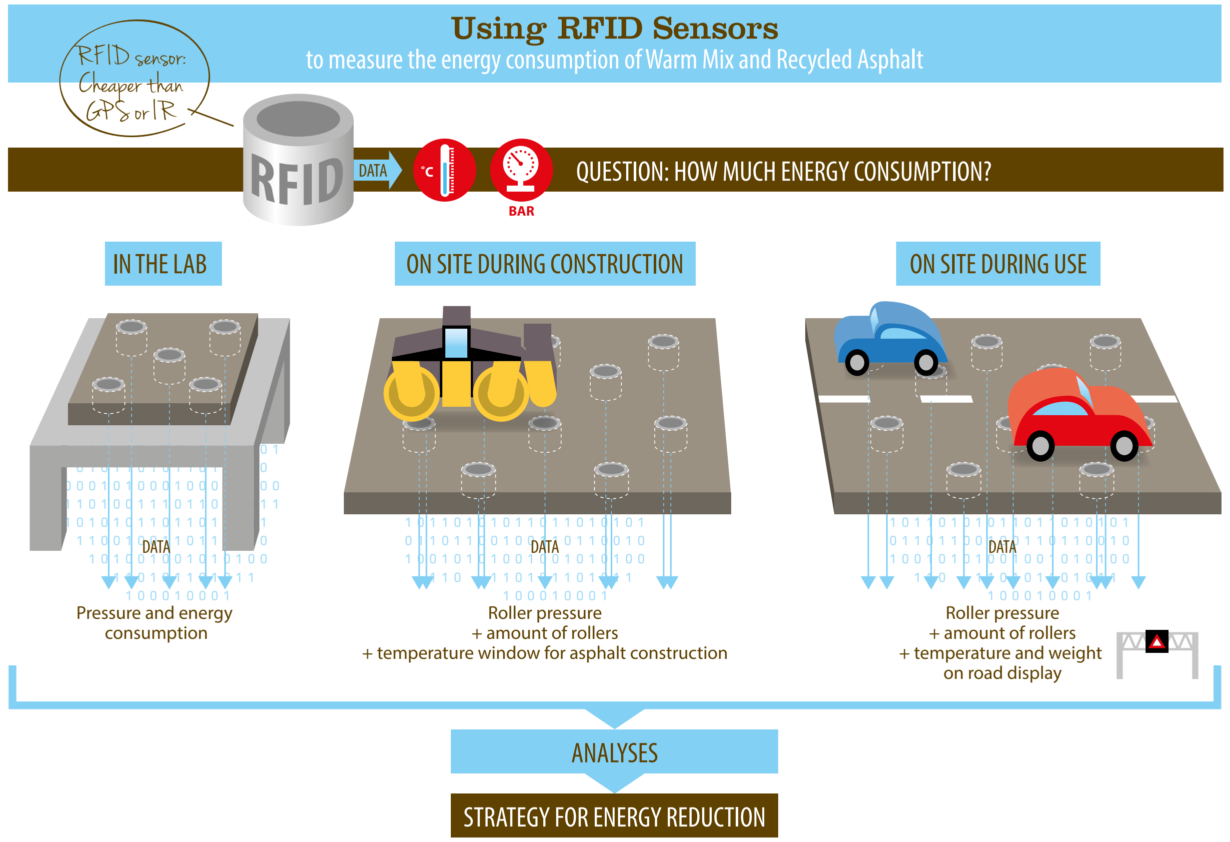
Mounting the RFID sensor with molten mastic asphalt proved indeed to be the most secure method during several field tests. A comparison of the core temperature measurements using the thermocouples and RFID sensors shows good correlation between the respective cooling curves and a difference of ±2°C between the in-asphalt temperature measurements. This difference is not considered significant given the temperature ranges in which compaction takes place. The RFID sensor is most reliable with no failures during the on-site tests. However, the thermocouples reliability is questionable given inaccurate results in two tests. This probably occurred because thermocouples tend to move under compaction. The surface temperature measurements correlate well with the sensor's in-asphalt measurements and as expected, are lower given the water used during compaction and ambient weather conditions.

Vehicle Load Simulator Tests

The Road and Railroads Research Laboratory of Delft University of Technology has a linear accelerated testing facility, LINTRACK. Since no suitable pressure sensor could be found, work at the facility focused on the integration of the temperature sensor into the measurement process. The limitations of the RFID technology became immediately apparent given that the loading machine is located inside a temperature control room and has to be completely closed during testing. The reader's limited reach resulted in no measurements being able to be undertaken in real time. For field applications this means that the road needs to be closed to traffic to take readings, which seriously limits the applications. The sensor was, nevertheless, able to withstand the heavy vibrations and harsh environment of the LINTRACK facility evidenced by the successful temperature measurements taken afterwards and with no apparent damage to the sensors during testing. Also, in this project the sensors are placed underneath Hot Mix Asphalt (ZOAB) and they withstood those temperatures without damage.

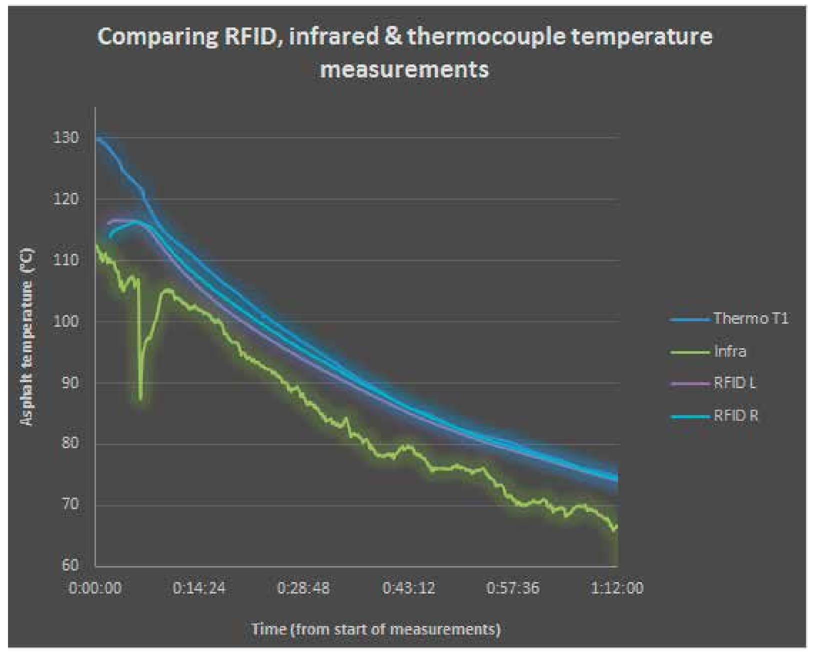
Project Enschede – Long Term Temperature Monitoring

In cooperation with the Gemeente Enschede, several RFID sensors are currently being installed in newly constructed surfacing layers in the city. The installed sensors will be monitored by ASPARi researchers over the next two years to assess its long-term monitoring capabilities, especially during the winter months.



RFID temperature sensor mounted on a mastic asphalt block

RFID sensor still intact (and working) after the compaction process



Typical field test results

University of Twente
dr.ir. **Seirgei Miller, Denis Makarov, Sjon Van Dijk**

Delft University of Technology
prof.dr.ir. **Sandra Erkens,**
dr.ir. **Xueyan Liu,** dr. **Anupam Kumar**

Asfalt Centrale Hengelo
Jeroen van der Spiegel, Ferry Lochtenveld

BAM Wegen
Marco Oosterveld

Twentse Weg en Waterbouw
Chiel Harmse, John Snippert

Gemeente Enschede
ir. **Jan-Paul Boutkan**

Promising Benefits for Monitoring Temperature but …..

The results of this project show that the passive RFID sensor is a feasible technology to monitor temperature progression during construction albeit for asphalt having an upper temperature threshold of approximately 125°C. It also appears feasible for monitoring asphalt temperature during winter periods when freeze-thaw cycles may damage and reduce the performance of the asphalt layer.

However, while the technology is promising, the study has highlighted limitations. Firstly, the absence of a suitable pressure sensor to capture the density progression during compaction activities is disappointing. Secondly, the limited temperature range probably excludes it being applied to the majority of HMA mixtures here in the Netherlands, although in the TU Delft application they were used under HMA. Thirdly, taking sensor readings is labour-intensive and cumbersome given the need to place the reader very close to the sensor (within 20cm) to take accurate readings. This presents significant safety problems in a heavy machinery environment and in heavy traffic during the life of the asphalt layer. Also, considering the size and the precautions needed to place the sensors, adding them in bulk for track & trace pavement management is not yet feasible.

Applying appropriate sensor technology in the asphalt construction process requires predictable and reproducible sensor performance given the nature of the asphalt construction process. Placing any sensor in the asphalt layer during construction is both challenging and promising. It is challenging since it needs to be done in a non-invasive manner and in such a way that it does not disturb the very properties being measured. Promising, since if done properly, it opens up opportunities for measuring a range of properties during and after construction given the rapid development of sensor technology. The work into studying suitable sensors, sensor modalities and wireless communication will continue given the results of this project. Further industrial partners are invited to contact us and discuss the possibilities.

ROBOTICALLY DRIVEN CONSTRUCTION OF BUILDINGS

Robotically Driven Construction of Buildings (RDCB) is an exploration into holistic/integral design to production solutions for robotically driven construction of buildings by involving the disciplines of architecture, robotics, materials science, construction and building technology, and structural design. The team integrates knowledge from the individual disciplines in order to develop new numerically controlled manufacturing techniques and building-design optimizations for adding creative values to buildings in a cost-effective and sustainable way.

This project is in line with Europe's aims for improving material sustainability and energy efficiency of buildings and construction processes. Robotically driven construction and customized building material systems have the potential to realize this in a cost-effective way and at the same time reduce accidents and health hazards for workers in the building sector. In order to achieve this, RDCB is distributing materials as needed and where needed. This requires exploration of a variety of techniques and implies working with customized materials while finding the best methods of applying materials in the logic of for example specific force flows or thermal dissipation patterns.

RDCB advances multi- and trans-disciplinary knowledge in robotically driven construction by designing and engineering a new building system for the on-demand production of customizable building components. The main consideration is that in architecture and building construction the factory of the future employs

building materials and components that can be on site robotically processed and assembled.

At the Delft University of Technology (TUD) two groups of researchers and students have explored possibilities of implementation of robotics in architectural design and building material systems. While at the Civil Engineering Department the focus was to study the production of suitable recycled fine aggregates to be used in robotically aided construction processes, for the Hyperbody group at the faculty of architecture at TU Delft, the focus was on developing a robotic setup as an integrated design to production system for Additive Manufacturing supported by customized Computer Aided Design procedures.

The aim of the project at Eindhoven University of Technology (TU/e) was to create knowledge about robotically construction methods and possible applications of this methods. The process was divided into different stages: brainstorm sessions, design meetings and the realization of the product. It has been done with a team of students with different backgrounds: Structural Design (SD), Building Technology (BT) and Construction Technology (CT).

The first meeting introduced the purpose of this project: a robotically created product for the building industry. Because of the variation in building industry disciplines the TUE group was divided into brainstorm teams with the specializations SD, BT and CT. Every discipline explored what they could do with robots within their own specialization. The directive given was: think about possible design-optimizations in order to improve, for example, sustainability, durability, material-usage and space-usage. In this process the students created their own visions about the new design possibilities considering different robot construction methods. This resulted in three different ideas with common points: building design adaptability, unique shapes (greater design freedom) and effective integration of different disciplines in construction components. The team of TUE continued with studio RAP a design and fabrication studio focusing on robotically controlled fabrication methods within the building processes, to design the possible scenarios for realization of the prototype with the robot.

At Delft, the process of experimentation with robotic arms started in the beginning of the project to inform the design processes at the very early stages to establish a direct link between design and production. This way the team was not only able to explore different design variations and possibilities to be produced only by robotic 3D printing, but also was able to adjust, customize and develop the required design tools to production system, considering both material behaviours and the evolving design outcomes.

Objectives and Ideas Behind Making the Prototypes

TU/e;

- A façade of a building with a segment of a floor.
- optimizing the geometry based on structural behavior.
- Open parts of the optimized topology of the façade to be used as 'windows'.
- The floor-construction is inspired from a leaf's shape, and thicker parts in the floor can be used for tubes and installations.
- Using robotic subtractive methods of production to create complex moulds to cast the designed parts in concrete

TUD;

- Developing and establishing proper computational design methods for a compression-only structure considering the innate characteristics of the material.
- Translating the results of design and material distribution analysis into robotic motion paths for material deposition.
- Making a part of the designed pavilion with the developed robotic 3D printing

Delft University of Technology
Dr.-Ing. **Henriette Bier,**
M.Arch. **Sina Mostafavi,**
ir. **Ana Anton,** ir. **Serban Bodea,**
Berend Raaphorst, Guus Mostart,
Hans de Jonge, Jeroen van Lit,
Jan Paclt, Kasper Siderius,
Marco Galli, Michal Kornecki,
Mohammad Jooshesh Oana,
Anghelache Perry Low,
Radoslaw Flis, Rob Moors,
Rutger Roodt, Ruth Hoogenraad,
Stef Hoeijmakers, Steph Kanters,
Thijs IJperlaan, prof.dr. **Peter Rem,**
Somayeh Lotfi, Eleonora di Domenica

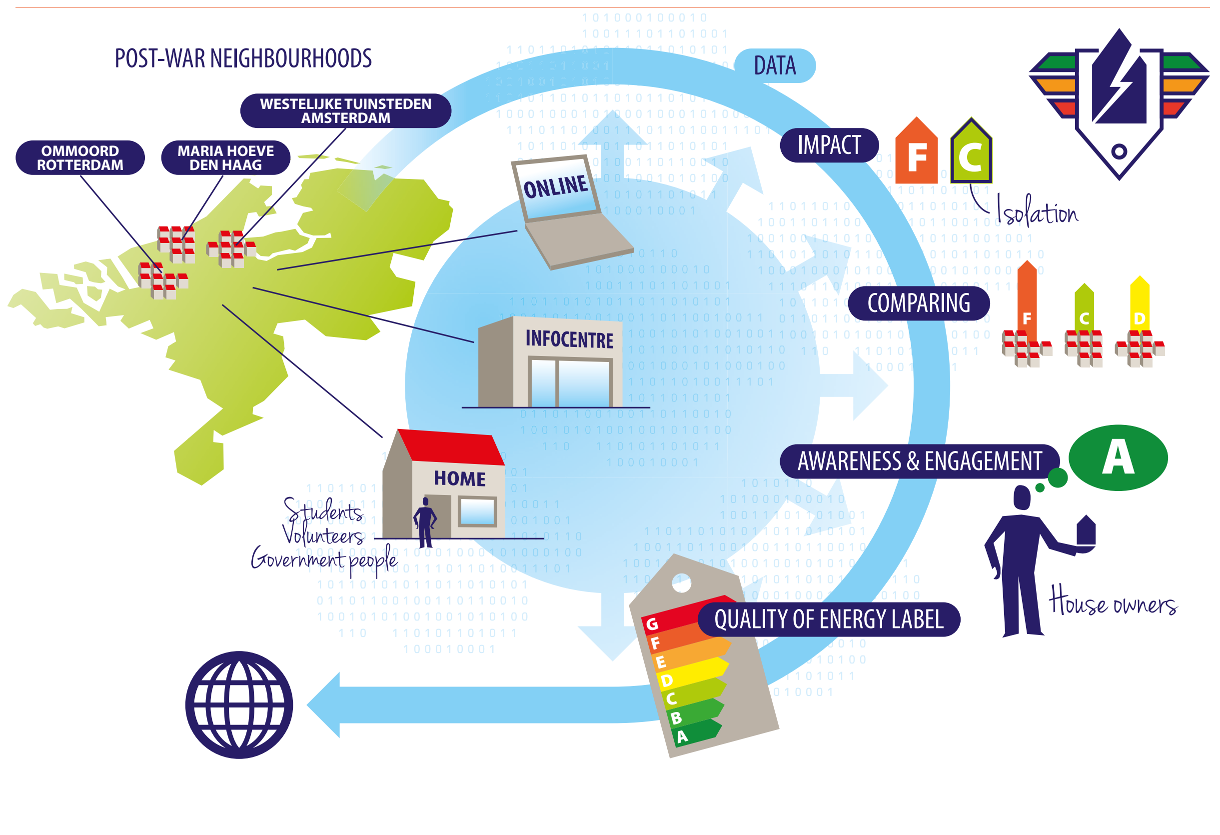
Eindhoven University of Technology
prof.dr.ir. **Theo Salet, Jordy Vos,**
Adrie van der Burgt, Bas van Wezel,
Christiaan Voorend, Chiel Bekkers,
Iris Rombouts, Luc Gerlings,
Marieke de Vries, Marijn Bruurs,
Rob Wolfs, Siert Saes, Tim Span,
Wout Rouwhorst

system for extruding clay ceramics.
- considering porosity of material in different scales ranging from Macro (scale of architectural elements like openings and building envelop) to Micro (scale of material distribution or material architecture).

The results of the RDCB project can be discussed at two levels of fundamental and applied research, which are realized through making the prototypes by each university. Researchers at the civil engineering department of TUD have made studies on recycled concrete as well as studies on the use of possible natural materials on a fundamental level. The applied research of the Hyperbody group can provide the required supporting knowledge for further improvement of application of robotic additive manufacturing in the building industry. In combination, the results of on the one hand material based research as the development of computational and parametric design strategies can bridge the gap between early stages of design and production process.

At TU/e, analysis of the experienced design to fabrication process, using a robotic subtractive manufacturing method can lead to a comparison between CNC milling methods with robotically supported manufacturing techniques to specify the advantages of application of robots or robotization in some parts of building industry.

Eventually both series of experiments and prototypes - the casted concrete components of TU/e in robotically produced moulds and porous robotically 3D printed building prototypes of TUD in ceramics – specify to a certain degree what is possible and what is not and can define the future roles of robotics in building industry. In this context, the next step for future explorations and prototyping can focus on simultaneous and/or sequential combination of these processes, supported by multiple robots to illustrate and define some of the characteristics of future programmable building factories.



SAVING ENERGY BATTLE

Energy efficiency is a priority to many cities, with programs being implemented to stimulate energy savings in the built environment. Cities aim to reduce carbon footprint, but also to cut energy costs. This has led to urban renewal developments, where neighborhoods were demolished and replaced by new neighborhoods, assumingly more sustainable. Some neighborhoods built during the post-war period are now under trial for their poor materialization and energy inefficiency. Though, they are also the massive expression of a rising idealism from the 20s and 30s, where public officers and professionals, as urban planners, architects and engineers had the opportunity to give the working class a larger, healthier and greener living environment. The demolition of these neighborhoods is accompanied by problems such as waste of resources, social segregation and cultural loss. Instead, the main energy and CO2 saving potential lies in the existing building stock (Petersdorff et al, 2006; Energy DG, 2013). Transformations can save not only energy costs, but also embodied energy. When it comes to heritage-designated buildings special attention should be paid to the preservation of their heritage values (Godwin, P. J. 2011; Alev et al. 2014). Their existence is not only embodied energy and carbon emissions, but also the spirit and identity of a community (Godwin, P. J. 2011).

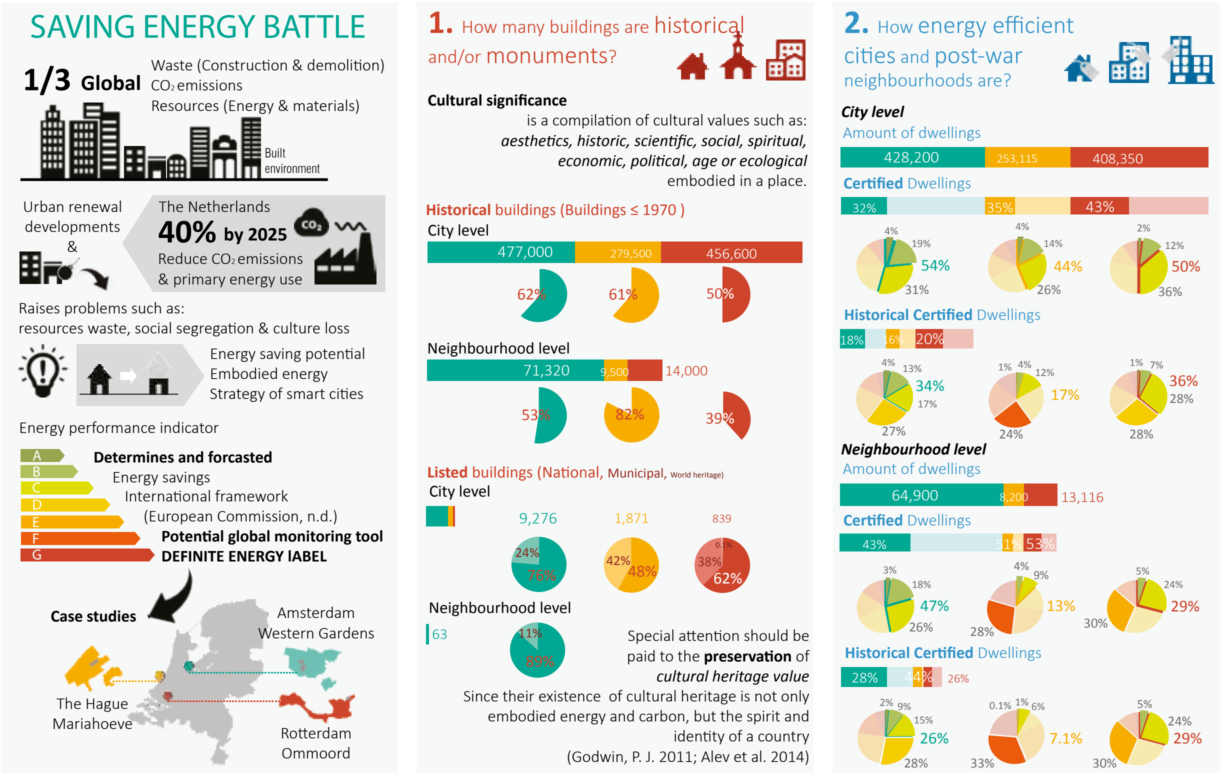
There is a growing body of knowledge on energy efficiency in the built environment, though, primarily derived from samples (Murphy, 2014), models (Melo et al., 2014), and/or buildings owned by housing associations (Nieboer et al., 2012). There is still very little known on the energy efficiency of post-war neighborhoods, and even less on the contribution of private homeowners' efforts to raise energy savings through the transformation of their buildings. Yet, their transformation patterns can feed the debate and help determine the energy efficiency of buildings and post-war neighborhoods. A framework for energy performance certification, as the Energy label, provides information on the energy efficiency of buildings, but also enables energy savings to be determined and forecasted. It also systematically records information about the building stock and its transformation. There is great criticism on the reliability of the Energy label, particularly on the new process implemented in the Netherlands since January 2015. Though, being an international framework (EC, 2015), there is great potential to keep developing it into a reliable global monitoring tool.

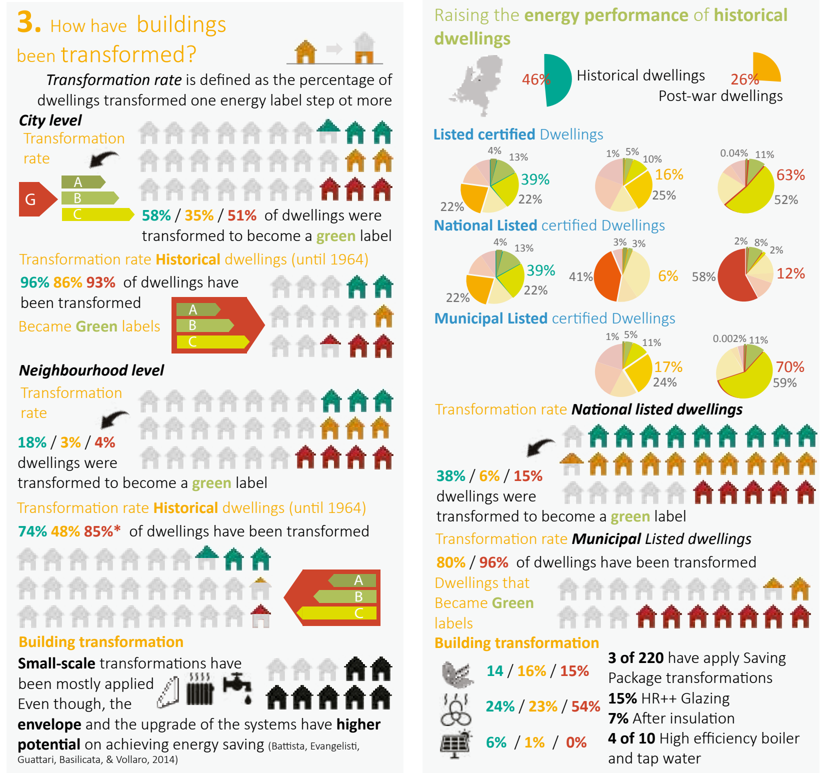
This research focused on unveiling the role of historical buildings, and those designated as heritage, in particular, in raising the energy performance in three Dutch cities. Results reflect the correlation of three research questions, aiming to identify and classify historical buildings on their heritage designation, energy performance and building transformations. Dwellings are taken as case study, with private owners in particular, as they are now leading the new energy certification method. The correlation between the available data was made possible due to the common construction unit, based on the BAG (Basic Administration Addresses and Buildings). Buildings are distinguished according to their heritage-designation, as global (UNESCO World Heritage), national and municipal. The Energy label was used to derive the energy performance, as well as, the transformation rate, through the alteration of the Energy Label over time. And finally, more information about building transformations, such as the rationale to implement them, was gathered during the event 3TU Saving Energy Battle (sEB).

sEB

The sEB took a first step in this global monitoring tool (http://savingenergybattle.nl/), by testing this new process of energy performance certification (Definite Energy label), in three post-war neighborhoods of Dutch cities: Westelijke Tuinsteden, Amsterdam; Ommoord, Rotterdam; and Mariahoeve, Den Haag. This monitoring tool was organized as a live event where the staff and students from TU/e and TUDelft, as well as, volunteers teamed up to assist building owners to upload the requested information. The sEB was won by Den Haag (127), followed by Amsterdam (118) and Rotterdam (62). The results were shared and disseminated in a publication prepared by both universities. Previous to the event, the website offered short courses, created to ease the submission process. Nowadays, the website offers the timeline and outcomes of the sEB project.

Through this research, the Energy label has been successfully used to monitor the energy performance and transformation of buildings at large scale. It enabled us to compare and distinguish cities to neighborhoods, and historical to modern dwellings. Findings showed that post-war neighborhoods have a worse energy performance than their cities as a whole, evidenced by 20% less green labels. Historical dwellings have, on average, a lower energy performance than modern dwellings, which is more evident at the neighborhood level with an average of 10% less green labels. Historical dwellings in post-war neighborhoods are lagging compared to their transformation at city level, with around 20% less transformed dwellings. The results are more evident when analyzing the case of Mariahoeve.





Eindhoven University of Technology
Ana Pereira Roders,
Lisanne Havinga, Henk Schellen,
Bernard Colenbrander,
Michael Gravers, Anahita Haghparast,
Luuk Hermans, Else Ferf Jentink,
Sandra K. Sánchez de la Garza,
Eirini Sfakiotaki, Leon Tonnaer,
Laurie van Krugten, Tim Willems,
Peyvand Yavari

Delft University of Technology
Job Roos

Atriensis
Hella Maessen, Dave van der Helm

Van nut
Richard Verbruggen

Videohero
Ivan Elias Oliveira

Rijkdienst van Cultureel Erfgoed
Bill Wei

Rijksdienst voor Ondernemend Nederland
Monique Lacroix

Gemeente Amsterdam
Karin Westerink,

Gemeente Den Haag
Henk Bakker

Gemeente Rotterdam
Roland van der Heijden

Volunteers
Amsterdam: **Bill Wei,**
Hannaneh Sobhani,
Romanos Dodopoulos,
Stefanos Andreou, Thomas Mathew,
Rishi Mohan, Martha Regis.
The Hague: **Saeed Masroor,**
Paula Stemkens, Harry Hermans,
Kees Hermans,
Sebastiaan van Ruitenbeek,
Alida Van Krugten.
Rotterdam: **Stephanie Leinders,**
Alice Tonnaer,
Franca Eurlings-Tonnaer,
Marie-Louise Tonnaer-Hoenen,
Frans Tonnaer, René Heuvelink,
Remko Huzen, Rowan de Nijs,
Esther Willems

The Energy Label

The energy label should be seen as a potential tool, to monitoring buildings on their energy performance, determining the impact of building transformations and underline potential areas of transformation. Post-war neighborhoods were built due to a housing shortage leading to a massive production of dwellings with similar characteristics, technical and cultural wise. Therefore, identifying the main sources of energy waste, solutions can be address at building level but applied to a bigger ensemble (block or neighborhood), enhancing the energy performance of the whole area and preserving its identity. Yet, these actions demand a close collaboration between the various stakeholders such as developers, corporations and most important municipalities (Bijlsma et al, 2008).

The potential of post-war buildings to raise energy savings is largely underestimated since the results show that energetic improvements are achievable. 77% of these dwellings were transformed and 11% achieved green labels. On average 41% of the measures studied were applied, in most cases this consisted of around 80% glazing, heating and tap-water systems. Without severe actions in the built environment the energy demand will increase 50% by 2050 (GNP, 2013). Therefore, urban planning and architecture should become stricter on how to transform the built environment towards sustainability, including renovations and heritage-designated buildings at best, as findings showed that their transformation is possible and happening, though with only a few energy saving measured and not on their full potential.

SEMANTIC WEB OF BUILDING INFORMATION

Information required by practicing architects, engineers, construction managers, building operators, asset managers, owners, and users becomes more and more distributed, detailed, and richer. BIG DATA is on the rise and this trend will not stop. We rather expect that this trend will further accelerate in the upcoming years as;

- **more and more sensor technologies will become widely available to access existing conditions in the built environment**
- **more and more information streams will be combined for various purposes, e.g. mobile data access information to space use in order to evaluate wireless infrastructure performance but also to establish building use patterns in post-occupancy evaluations**
- **advanced design tools will allow for more detailed data-driven simulation of an increasing number of design alternatives in shorter time spans**
- **participatory efforts will involve an ever-larger number of specialists and non-specialists that all provide information that needs to be accounted for during design and construction planning**

The availability of the above described BIG DATA will mean that data sources in the future will be based upon an increasing number of standards, information models, and semantic dictionaries. Additionally, data sources will become increasingly distributed across the web. Practitioners need to be supported in finding, combining, and acting on this distributed information. Already posing a problem for engineering practice today, in this changing world, humans will no longer be able to ensure the consistency of information and, more importantly, find the for them relevant information.

To this end, semantic web technologies are required that allow machines to readily interpret information and can perform much of the tedious and time consuming work involved in working with distributed BIG DATA repositories. After all, computers can support humans in indexing and searching data. We expect that this will be one of the most important and prominent areas for research in the upcoming years. In this lighthouse project, we made a number of first important steps to enable such research:

We set up a repository structure for storing building related information within an archive. This archive will allow us to collect all data that students at the 3TUs developed in the last years and will develop in the years to come. In collaboration with the FP7 EU project 'DURAARK', a repository for the sustainable long term preservation of digital building information in different formats, including the Open Industry Foundation Classes (IFC) has been created and will be filled over time. The repository, made available in the Amazon cloud by project partner Microsoft, can then be used by researchers to develop indexing and search solutions and to empirically test them. We also expect that the repository can grow into a benchmark for testing developed indexing and search algorithms with respect to their performance in terms of speed, completeness, and stability.

Map Making

We also made a first start for establishing a map of the available data formats, standards, and dictionaries to describe building related data. The map will provide an overview of the ontological spectrum within the field of civil engineering. The spectrum, in turn, will allow researchers to start developing different translation mechanisms between the different existing data formats, standards, and dictionaries to arrive at homogeneous indexing and search solutions in the long term.

A start was made to understand and develop future information use and exchange processes that assume a widely-distributed information environment. This part of the research is important to provide the basis for developing practically applicable indexing and search workflows.

A first step was made into exploring possibilities for automatically indexing the semantic information available within the large amount of existing data formats, standards, and dictionaries. Based on a selected number of case projects, first indexes have been extracted and explored according to their utility to support engineering work.

Conclusion

The above summarized four steps, even within the quite early stage of development they are in, provide a strong foundation for semantic web research at the 3TU in the years to come. The steps provide a platform and an initial research framework for academic research at the Bachelor, Master, and PhD level.

University of Twente
dr. **Timo Hartmann**,
prof.dr.ir. **Arjen Adriaanse**

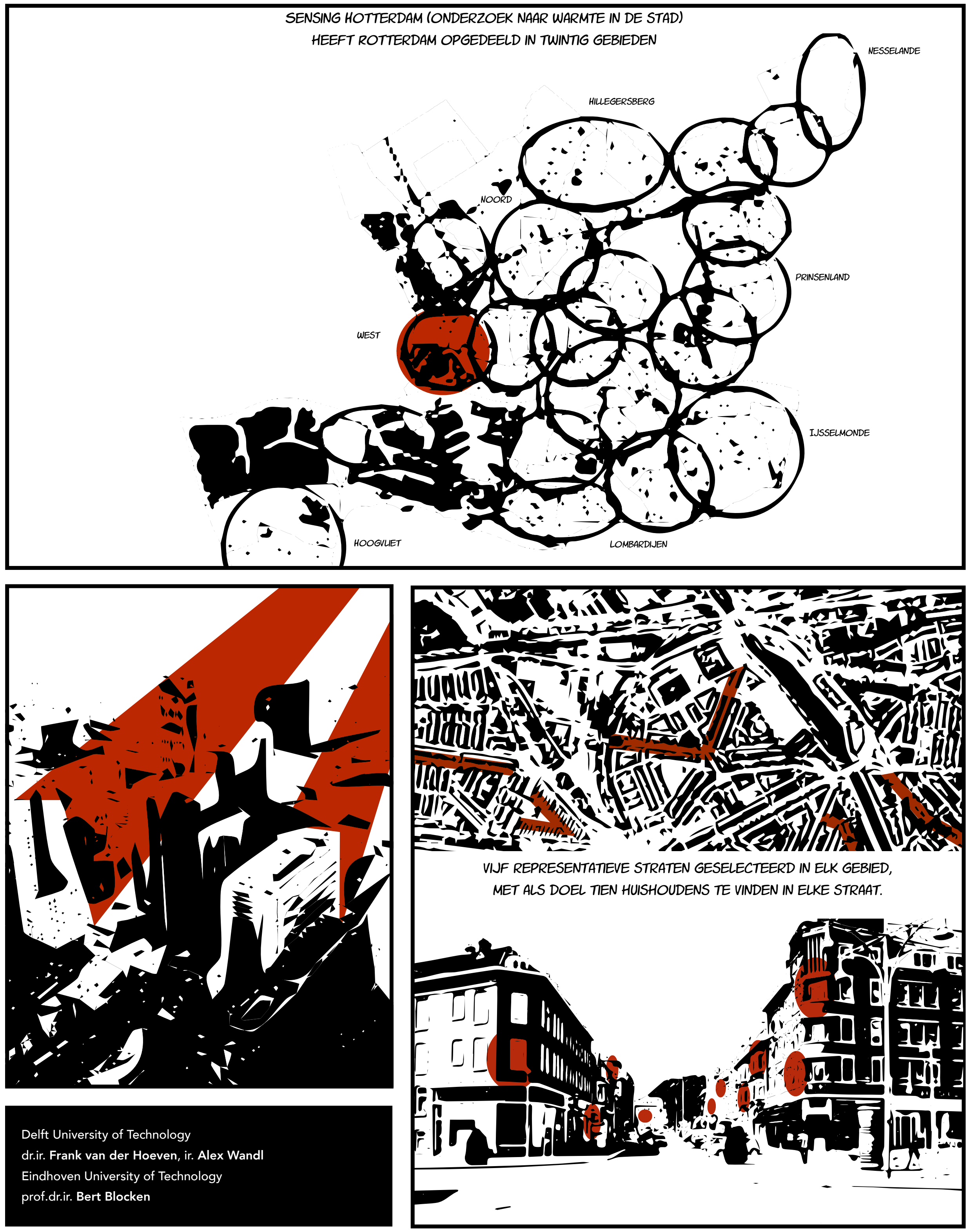
Eindhoven University of Technology
dr.Dipl.-Ing **Jakob Beetz**,
ir. **Thomas Krijnen**

Delft University of Technology
dr.ir. **Alexander Koutamanis**

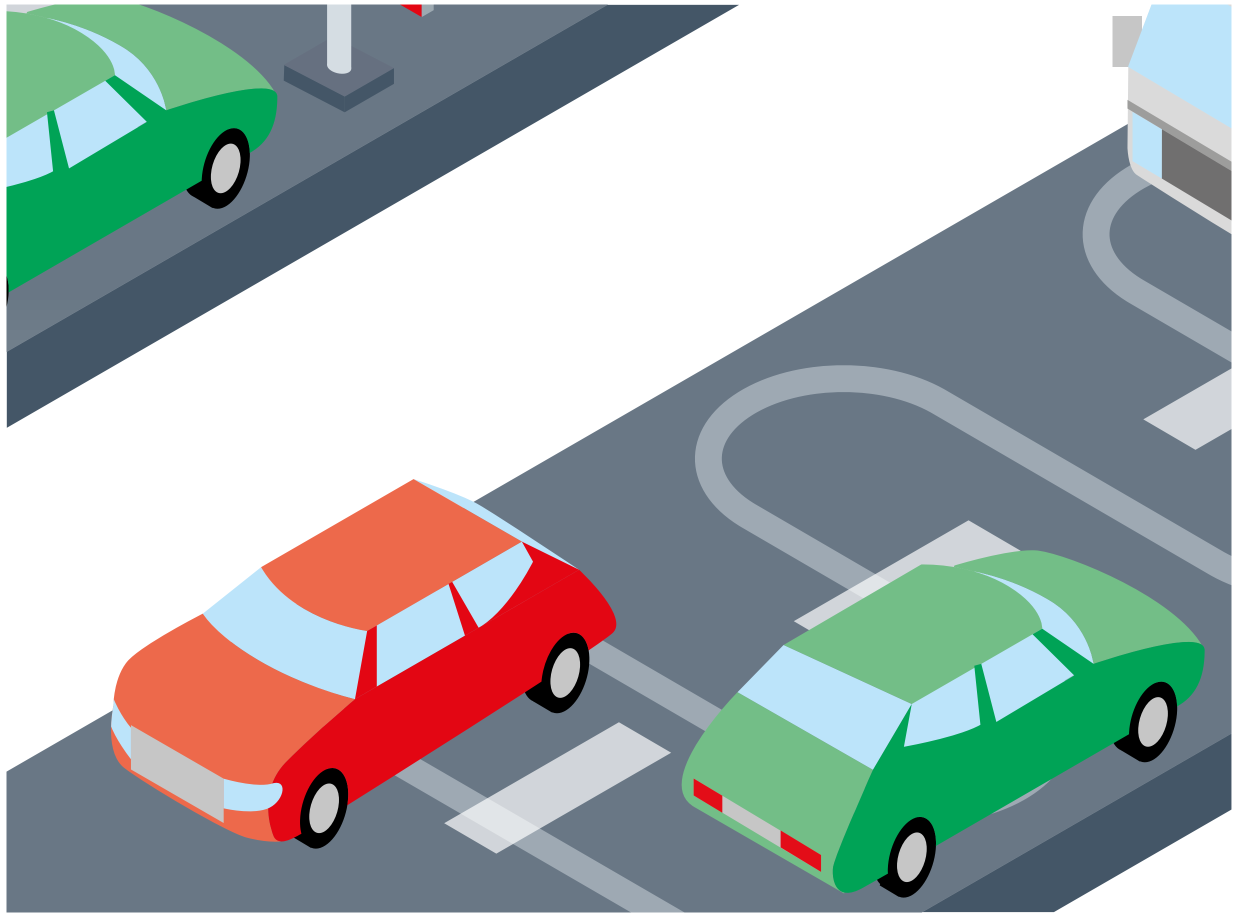
Balast Nedam

Microsoft Netherlands

SENSING HOTTERDAM



Delft University of Technology
dr.ir. **Frank van der Hoeven**, ir. **Alex Wandl**
Eindhoven University of Technology
prof.dr.ir. **Bert Blocken**



SMART SENSORS IN ASPHALT

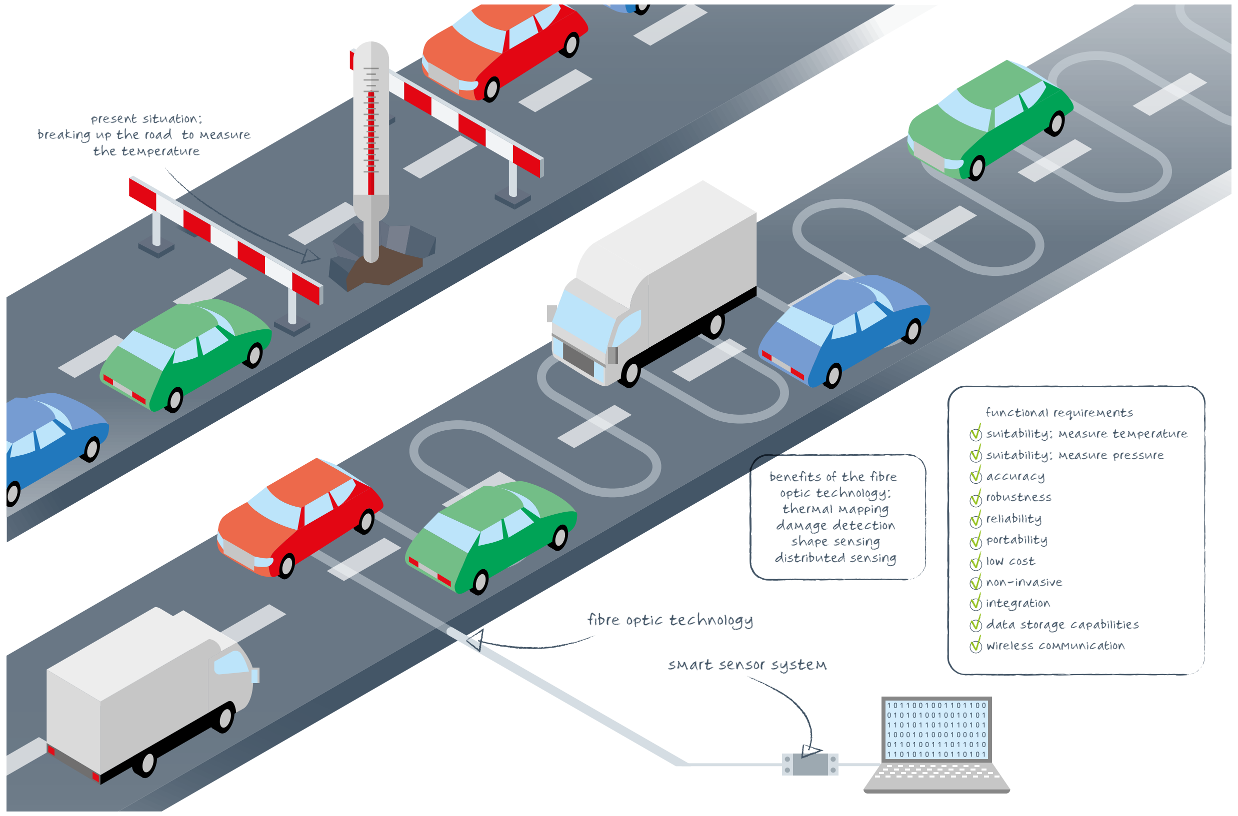
The Fibre Bragg Grating (FBG) technology based on integrated photonics, offers specific benefits including thermal mapping, damage detection, shape- and distributed sensing. This makes it useful for determining pavement behaviour during extreme weather conditions e.g. freeze-thaw cycles when harsh winter conditions could damage an asphalt surfacing layer. However, harsh construction conditions and heavy compaction loading highlights the high-risk challenge of installing this rather fragile fibre optic technology into the asphalt layer during actual construction operations.

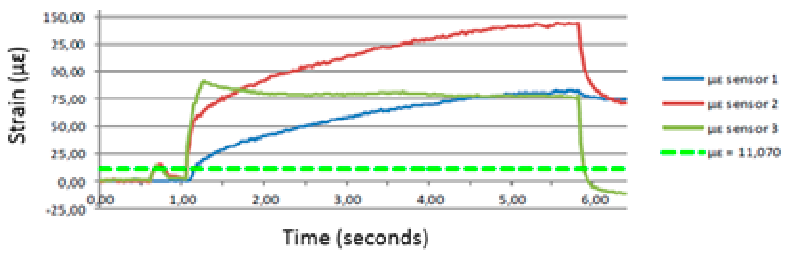
This project focuses on the integration of FBG into the asphalt construction process so that the technology's benefits can be realised for constructed asphalt layers. Accurately monitoring key process parameters during and after construction using the appropriate sensor technology should contribute to extending the service life (durability) of asphalt pavements.

FBG sensors have previously been successfully used to monitor strain and other parameters in asphalt. While previous projects have mainly focused on the installation of the fibre optic technology sensors after construction has been completed, this project takes on the challenge of installing the FBG sensors in a non-invasive manner during the harsh asphalt construction process. This raises significant challenges given high asphalt temperatures during construction, heavy roller compactor loading and the resulting shear stresses between aggregates which could damage the sensors during the construction process.

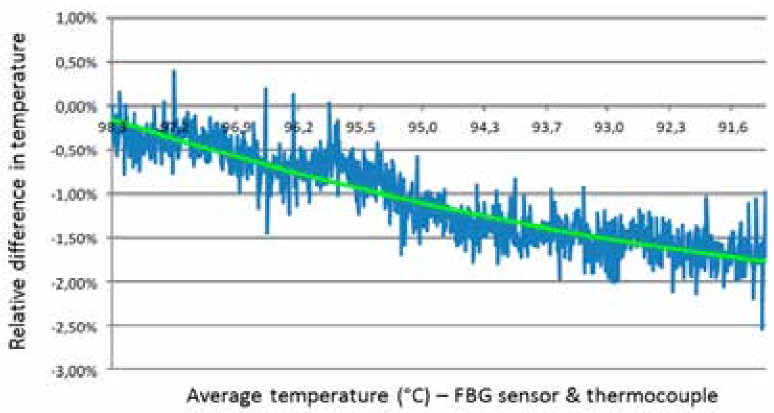
An initial part of the project included devising a set of functional requirements for the sensor system keeping in mind the harsh conditions that the system had to operate in during the construction process and afterwards during the service life of the asphalt layer. More importantly, to serve as a health condition monitoring system for constructed asphalt layers in the future, issues of system robustness, data accuracy, data redundancy, flexible installation and mounting, data transfer and data storage needed to be addressed in the design. To this end, several laboratory experiments were set up at Technobis, the fiber optic supplier and at local contractor, Boskalis.

A first series of experiments focused on getting to know the workings of the FBG sensors and testing a few of the functional requirements in a "dry" set up. The "dry" set up typically consisted of sensors mounted inside moulds that were filled with various raw aggregates or with cold mix asphalt. This enables checks to be made on the mounting of the sensors, the accuracy of the temperature and strain data with little danger of losing any sensors during this phase of testing. A second series of experiments focused on trialing several sensors set ups in Hot Mix Asphalt. More importantly, it focused on the protection of the FBG sensors given the very high asphalt temperatures and heavy compaction loading during construction. The protection of sensors has repeatedly been raised as a challenging issue to deal with in an extensive literature review. Several protection measures including Fibre Reinforced Polymer (FBR), steel tubing and carbon fibre reinforced epoxy resin coatings have been shown to provide adequate protection. Strain compatibility of the sensor to the package is important due to the actual strain measurement of the surrounding environment. In short, proper protection of the sensors was confirmed as key to the successful implementation of the FBG technology during both phases of laboratory testing.





Typical asphalt strain measurements using Fibre Bragg Gratings



Typical asphalt temperature measurements using Fibre Bragg Gratings

In a parallel exercise, several FBG sensors have been installed in an existing porous asphalt (ZOAB) layer at TU Delft's linear accelerator LINTRACK facility. The purpose is three-fold. Firstly, to assess the influence of sealing fluids such as epoxy or bitumen on the accuracy of the temperature and strain measurements. Secondly, to compare the accuracy of the collected strain data with the data collected from a previously installed strain gauge. Lastly, the collected temperature data should provide more insights the behaviour of the porous asphalt layer during freeze-thaw cycles in typical Dutch winters.

The results thus far, show that the FBG sensor is a feasible technology to monitor strain and temperature progression during asphalt construction and afterwards during the service life of the asphalt layer. The sensor can withstand high asphalt mix temperatures up to 200°C. It also appears feasible for accurately monitoring asphalt temperature during winter periods when freeze-thaw cycles may damage and reduce the performance of the asphalt layer. Laboratory tests using a 2ton "baby" roller compactor show that the sensor is able to deliver accurate strain measurements even under heavy loading. The strain measurements when combined with the temperature measurements, can be used to develop compaction and other performance models. Also, the strain measurements can be used to make explicit vehicle (axle) loading and therefore provide opportunities for assessing long-term damage due to for example, the overloading of trucks.

However, while the technology is promising, the study has highlighted a serious limitation. Fiber optic sensors are fragile, break easily under loading and therefore need suitable protection if they are to be installed during the harsh construction process. While several protection measures were tested during this study, more work is needed to find an appropriate protection method that guarantees the accuracy of both strain and temperature measurements. The results of ongoing long-term testing at TU Delft's LINTRACK facility, will show whether post-construction installation has any effect on the accuracy of the collected data and whether cutting grooves into the asphalt layer after construction has been completed is a feasible method of installation for collecting accurate temperature and strain data during the service life of the asphalt layer. The study will also address issues of damage to the asphalt layer given the invasive manner of installing the sensors after construction has been completed.

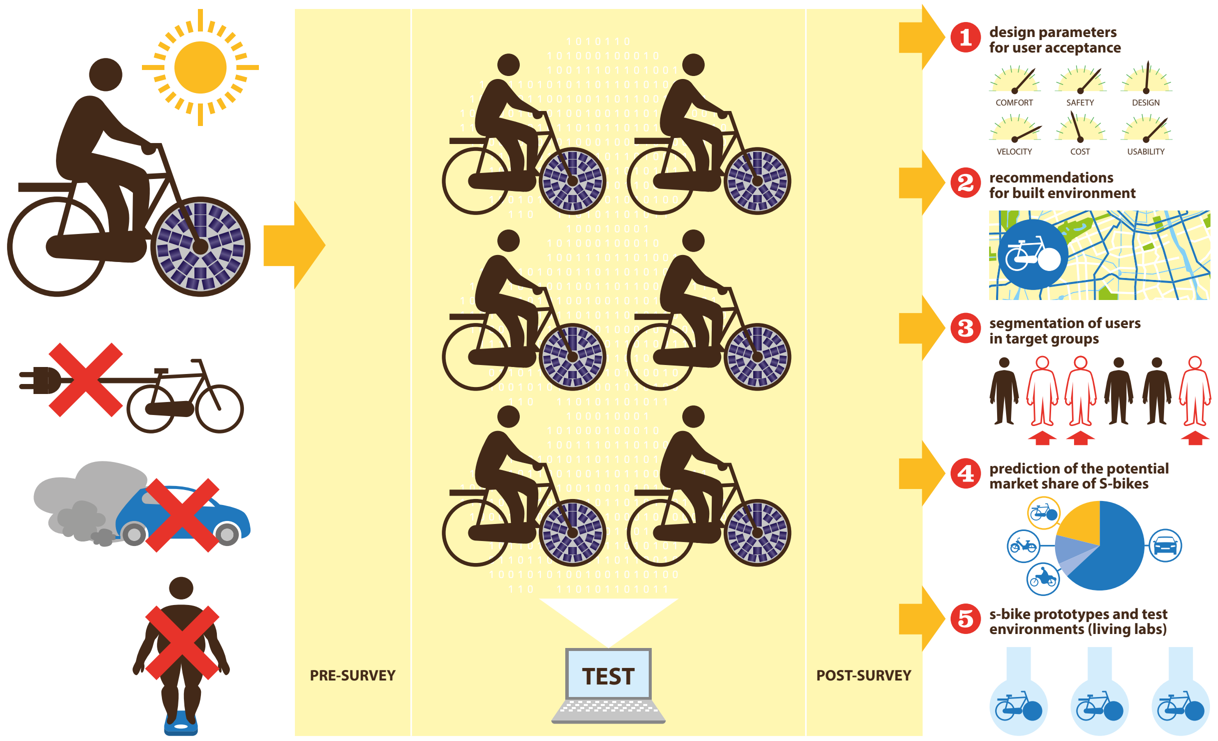
Applying appropriate sensor technology in the asphalt construction process requires predictable and reproducible sensor performance given the nature of the asphalt construction process. Placing any sensor in the asphalt layer during construction is both challenging and promising. It is challenging since it needs to be done in a non-invasive manner and in such a way that it does not disturb the very properties being measured. Promising, since if done properly, it opens opportunities for measuring a range of properties during and after construction given the rapid development of sensor technology. The benefits of thermal mapping, damage detection, shape- and distributed sensing, makes it useful for determining pavement behaviour during service life of the asphalt pavement and for working towards increasing the service life and therefore, the durability of asphalt layers. The work into studying suitable sensors, sensor modalities and wireless communication will continue given the results of this project.

University of Twente
dr.ir. **Seirgei Miller**,
mr. **Joyraj Chakraborty**,
Jurian van der Vegt, Daan Brinkerink

Delft University of Technology
prof.dr.ir. **Sandra Erkens**,
dr. **Xueyan Liu**, dr. **Kumar Anupam**

Boskalis BV
mr. **Berwich Sluer**,
dr.ir. **Mohamad Mohajeri**

Technobis



SOLAR BIKES: USER ACCEPTANCE

Car traffic causes carbon emissions and air pollution and has negative effects on public health and quality of life in cities. Solar bikes are an innovative, sustainable transport option that can offer a substitute for car travel. Solar bikes are electric bikes with solar cells that are powered by the sun. This expands their range compared to regular e-bikes as the bikes are charged during the trip and at the destination without electricity. The aim of this project is to understand people's preferences, conditions for acceptance and experiences with the solar bike. Insight in preferences and experiences will assist urban policy makers in identifying which interventions in the built environment can stimulate the acceptance and use of solar bikes.

Cycling has several benefits compared to motorized travel: it is cheap, environmentally friendly, and it is good for public health. Policy makers therefore promote cycling, even in the Netherlands, where cycling is already quite popular compared to other countries. In the Netherlands around a quarter of all trips are made by bike. However, bikes are mainly used for short distances up to 7.5 kilometers, while the average commute distance is 17.5 kilometers.

E-bikes may be a feasible transport mode for these longer trips between 7.5 and 17.5 kilometers. The pedal support of e-bikes allows cycling longer trips compared to a regular bike. E-bike ownership and use has raTpidly increased over the last decade.

Eindhoven University of Technology
dr.ir. **Pauline van den Berg**,
prof.dr. **Theo Arentze**

University of Twente
prof.dr.ing. **Karst Geurs**

A new type of e-bike, the solar bike, has recently been developed at Eindhoven University of Technology. The solar bike is an electric bike with solar panels in the front wheel that charges through sunlight. The solar bike thus has the advantage of a larger range and independency of charging compared to a regular e-bike.

In this 4TU.Bouw Lighthouse project, Eindhoven University of Technology and University of Twente study which factors affect the acceptance of the solar bike. This is done in three steps. First, a survey is used to collect data on people's perceptions of the solar bike, and under which conditions they would purchase and use a solar bike. The second part of the study consists of a field test in which participants will test the solar bike for one week. In the final part the participants who used the solar bike will be asked about their experiences in a survey as well as in focus group discussions.

In the first part of this project data have been collected using an online survey. The survey has been distributed through different channels, such as Facebook, LinkedIn and an email to the employees of the two universities. This has resulted in a sample of 317 respondents. A bit more than half (57%) of the respondents were men. Regarding age, 29% was below 30; 41% was between 30 and 49; and 30% was 50 years or over. Because the survey was distributed at the universities, higher educated people are overrepresented in the sample (89%).

Two thirds of the sample indicated that they considered purchasing a solar (very) unlikely. For 18% this would be neither likely nor unlikely, and 13% would probably buy a solar bike. The results showed that the oldest age group was more positive about the solar bike. Non-working and retired people were also more positive, and students were least positive. People who are more interested in innovative products are also more likely to purchase a solar bike.

In addition, the results of a choice experiment show that travel distance has the largest impact on the intention to buy a solar bike. People are most likely to purchase a solar bike when they have a commute distance between 7 and 12 kilometers, and least likely when they have a shorter commute distance.

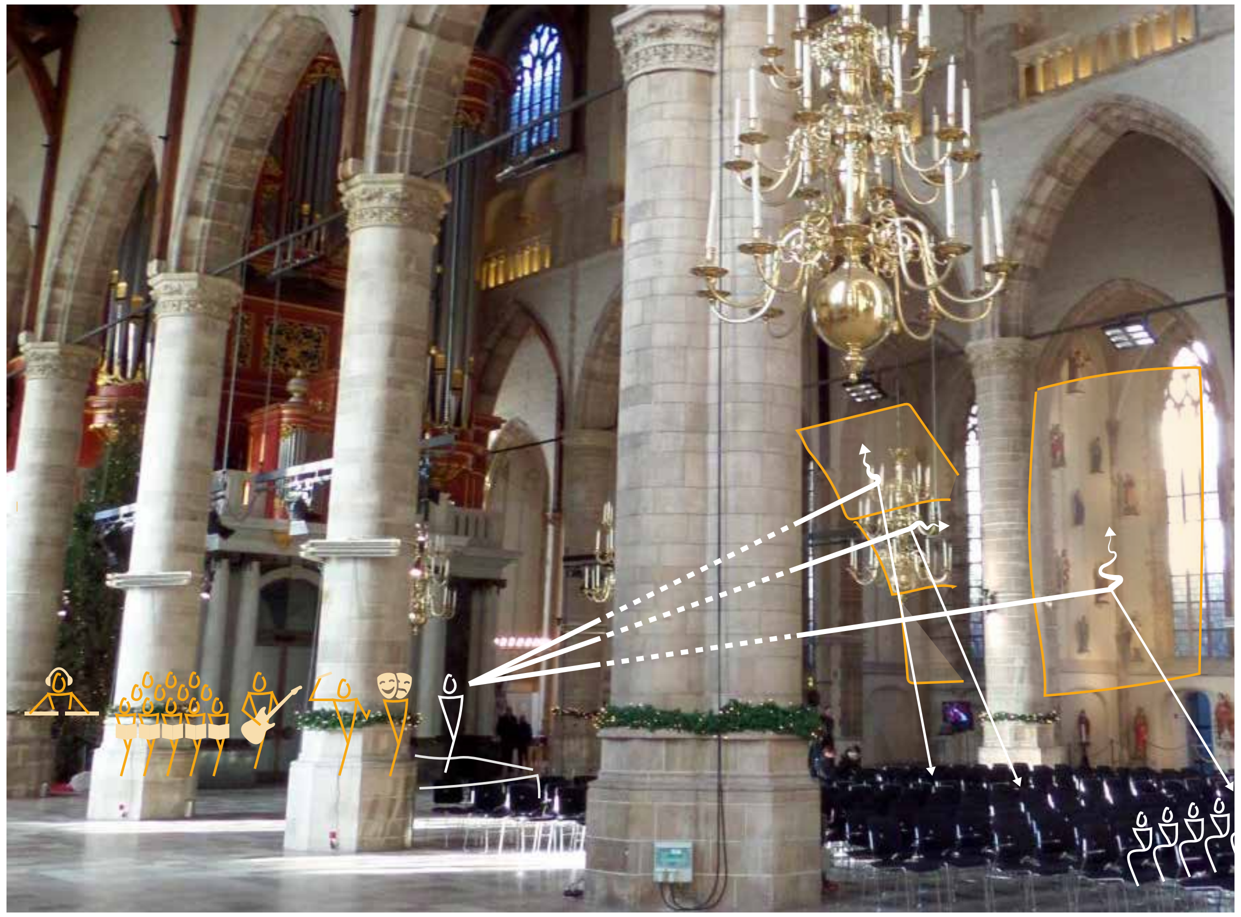
Good Infrastructure

The second most important factor is the quality of the cycling infrastructure. The better the infrastructure, the more likely people are to purchase a solar bike. People are also more inclined to purchase a solar bike when they can park the bike in a secured parking, when the quality of public transport is lower, and when car parking is more expensive. The characteristics of the solar bike itself also play a role. People are more inclined to buy a solar bike when it is cheaper and has a lighter weight.

Based on these results a number of policy recommendations can be given. As cycling has environmental and health benefits compared to car traffic, policy makers should stimulate cycling, also for longer distances. Good quality cycling infrastructure increases the intention to cycle, and to purchase and use a solar bike. Municipalities could therefore invest in the maintenance or improvement of bike lanes to stimulate cycling. As paid car parking has a positive effect on cycling, policy makers could also introduce this as a boost for cycling.

The developers of the solar bike could aim their marketing and sales strategy on the preferences of the main target group, consisting of people aged 50 and over. This could increase the acceptance of the solar bike.

The next steps in the project will be the field test and the evaluation survey and focus groups. The field tests will start in March 2017. This part of the project will reveil the actual experiences with the solar bike. It will also give insight in the question whether people's perceptions of the solar bike change as a result of testing the solar bike.



SOUND ABSORBING GLASS

Monumental buildings are demolished when they lose their traditional function. These historical monuments can be maintained by repurposing them for modern use, like lectures and musical events. This results in a demand for different acoustic conditions. However, monuments are subject to strict building intervention regulations; any intervention concerning changes to the original elements are often prohibited. This creates a demand for demountable and adaptable product design, repurposing monumental buildings by alleviating acoustical problems without distorting the view towards the monumental elements.

This research focused on developing sound absorption panels based on the micro-perforation principle: manufacturing these in thin glass panels, evaluating their influence on strength and transparency, optimizing sound absorption (perforation diameter and ratio) using a tailor-made computational model, and creating a pattern of perforations that optimizes strength.

Sound Absorption

To come to a product that can improve the acoustic surroundings in monumental buildings without affecting the beautiful sights, different aspects needed to be studied. The starting point became a micro perforated (transparent/glass) panel (MPP) in front, backed by a closed air cavity and an unperforated transparent back panel.

By manufacturing micro-perforations (≤ 1 mm diameter) in a thin transparent panel, sound absorption can be achieved due to viscous thermal dissipation inside these perforations, flow distortion effects at both sides of the panel and the acoustic resonances in the air cavity. During this study, many of such panels with different perforation diameters, perforation ratios, cavity sizes, panel thicknesses and combinations of differently sized perforations were tested in an impedance tube. This measures the normal incidence sound absorption: the amount of sound that is being absorbed of a certain frequency (range). We discovered that by solely using a single perforation diameter only a small frequency range was absorbed. Even though sound absorption is nearly perfect in that small range, our goal is to broaden this range in order to create improved acoustic surroundings for multiple, very different, types of events with accordingly different ranges of sound.

To come up with transparent sound absorbing panels with the highest sound absorption coefficient and the broadest frequency range, a mathematical model was developed. This model requires the following input parameters: perforation diameter, perforation ratio, depth of air cavity and the thickness of the panel. The model was validated making use of the measurements done in the impedance tube showing good correspondence, even for combinations of different perforation diameters and ratios within one panel. Making use of the validated computational model, optimum values for the input parameters are obtained, which will be used in the production of specified panels for a specific location.

Production Process and Strength

The production process of the panel had as a starting point: the use of glass, being the most transparent material available, and the thickness of the panel to be 2 mm, due to the limiting structural properties of float glass.

We tried three techniques to make micro perforations in glass, but hydrogen fluoride etching led to uncontrollable perforation sizes and shapes. But, there are two feasible ways to manufacture micro-perforations (≤ 1 mm diameter) in a glass panel: drilling or using a high-end pulse laser-cutting technique. These techniques are both as precise as leaving only 150 μm chip size around the cut, but the cost differs about 4:1.

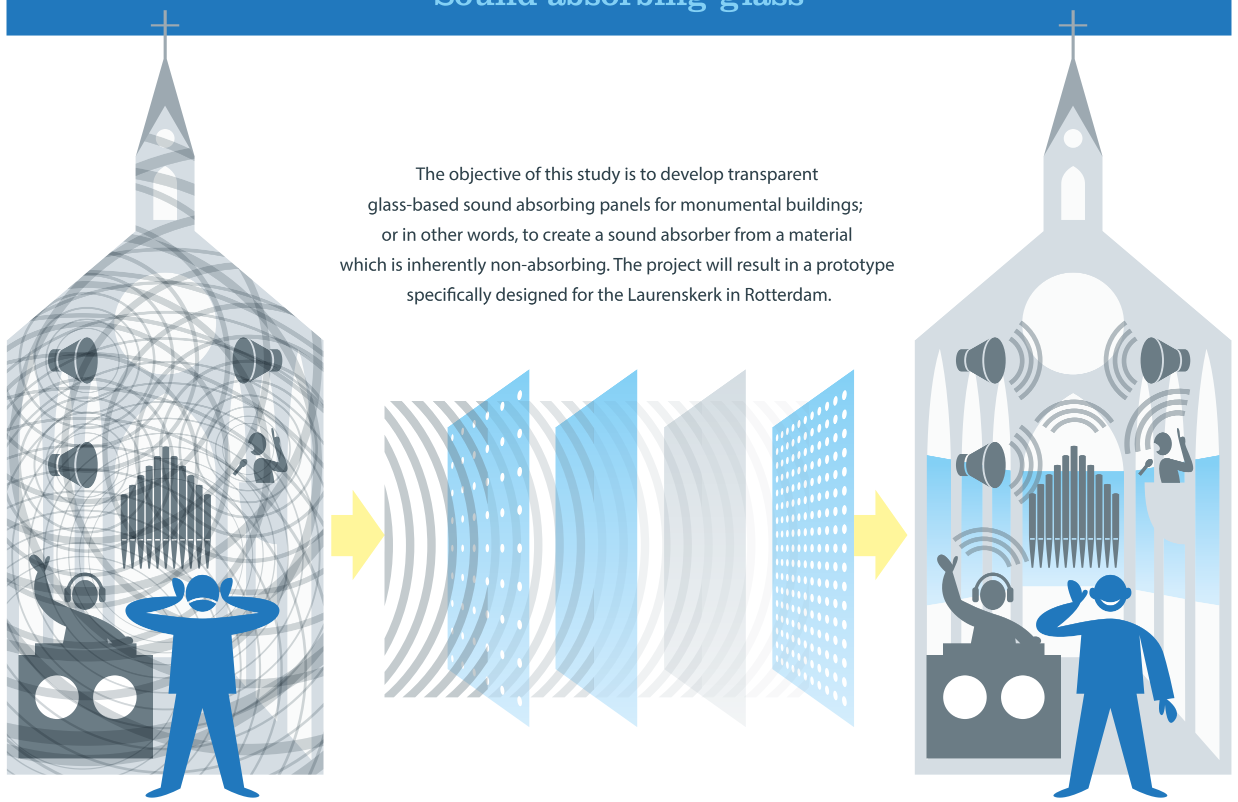
Perforations in glass panels cause stresses to course around these perforations throughout the glass panel, making its failure behaviour unpredictable and therefore its possible application not so obvious. The final product will contain many perforations, but failure will occur at the weakest point. So, to see that effect, a singular weak point (hole) was tested through computational finite element method (FEM) and a strength-experiment. The experiment is still ongoing.

Transparency

Another aspect of the finalised product is its transparency. This aspect entails two different scales: the smaller scale of the glass panel with the perforations and the larger scale, that of the entire composite panel and its support structure. The larger scale is dependent on the amount of 'edges' that obstruct the view behind the panel, i.e. frames, connections, cabling. Although the fixings and some connections could be made from the same transparent material as the panel, the structural components are inherently from different and opaque materials, so the less the better.

The smaller scale, that of the panel and the perforation itself and the pattern of the perforations, entails using a colourless glass or polymer with no light reflectance. Colourlessness can be influenced by the chemical composition of the material and the reflectance of the panel can be diminished by adding an AR-coating.

Sound absorbing glass

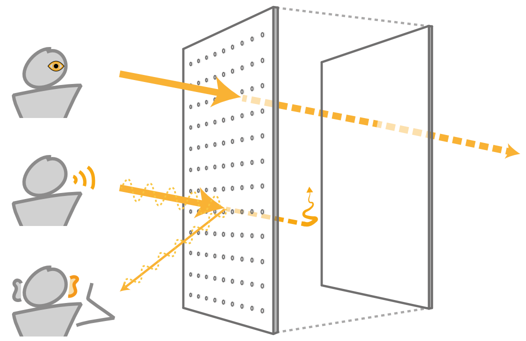


Looking at the perforation itself any manufacturing technique 'scratches' the material and thereby leaves a white edge inside the perforation. However, those perforations can then be treated by flame polishing or acid etching. This would not only make the edges transparent again, but also alleviates the tension in the edges, giving back some strength to the panel itself.

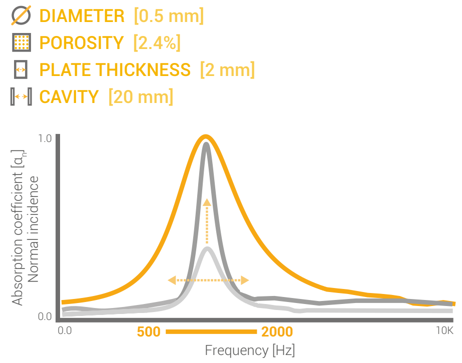
Even though the edges of the holes can be transparent, light breaks differently inside the glass than inside the perforation. This entails that perforations do slightly affect view quality: having a negative impact on the amount of detail visible of the image behind the panel.

Conclusion

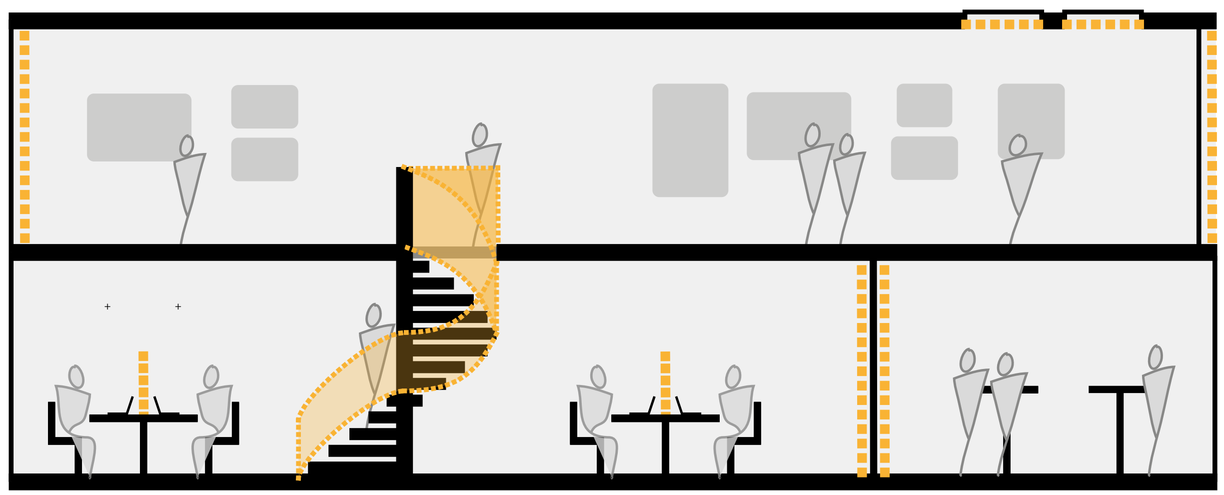
The present study shows promising results to bring sound absorbing glass into the building industry. Research is ongoing to reach the optimum integral design of the panel taking into account the sound absorption, transparency, strength and production costs. Besides creating different acoustic surroundings for different types of events in beautiful monumental spaces, the possibilities for application in other types of buildings and building-objects are endless.



Sound Absorption & Reflection



Broadband Sound Absorption



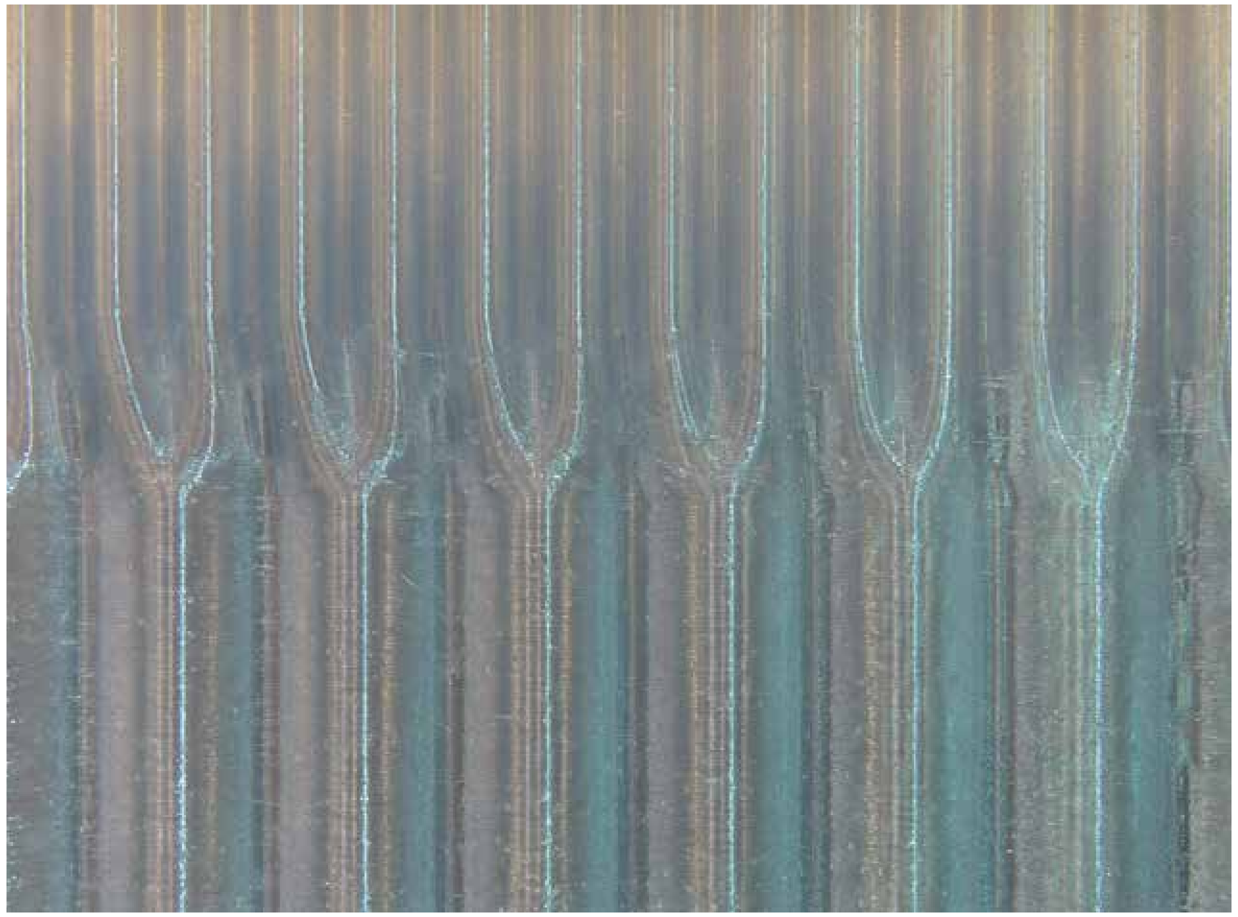
Future applications

Delft University of Technology
ir. **Anne Struiksma**,
dr.ir. **Martin Tenpierik**, ir. **Ate Snijder**,
dr.ir. **Fred Veer**

Eindhoven University of Technology
ir. **Bram Botterman**,
dr.ir. **Maarten Hornikx**

SiO2 glas
Hein van der Water

De Rotterdam
Frank Migchielsen



SPONG3D

Spong3D is an adaptive 3D printed facade system that integrates multiple functions to optimize thermal performances according to the different environmental conditions throughout the year. The proposed system incorporates air cavities to provide thermal insulation and a movable liquid (water plus additives) to provide heat storage where and whenever needed. The air cavities have various dimensions and are located in the inner part of the system. The movable liquid provides heat storage as it flows through channels located along the outer surfaces of the system (on the indoor and outdoor faces of the façade). Together, the composition of the channels and the cavities form a complex structure, integrating multiple functions into a singular component, which can only be produced by using an Additive Manufacturing (AM; like 3D printing) technology.

The aim of this research is a proof of concept of Spong3D. Spong3D is an adaptive façade system that controls the heat exchange during the year between the interior and exterior conditions of the building. It incorporates two sub-systems. The first system consists of a porous inner core with air cavities to provide thermal insulation. The second one contains a series of outer channels that enable the flowing of liquid. The liquid acts as movable thermal mass to provide adaptive heat storage. Based on necessity, the liquid can be transferred from one side of the façade to the other to absorb and release the heat. The overall adaptive system proposes an integrated component fabricated with additive manufacturing.

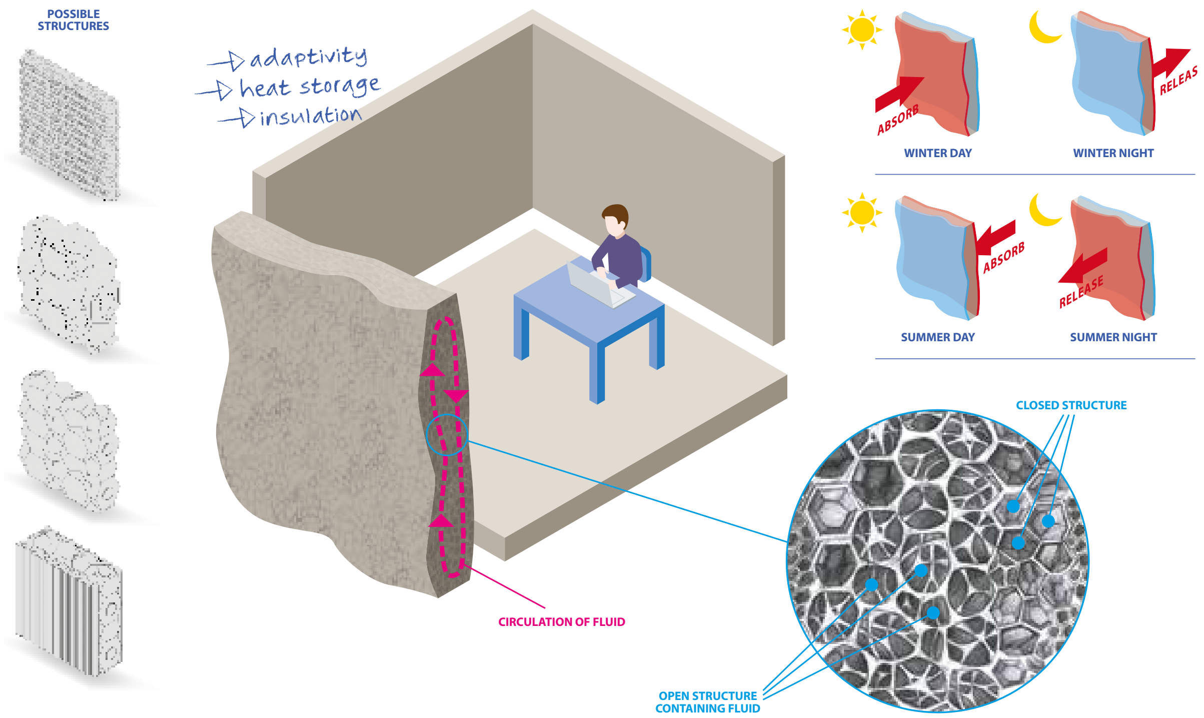
The development of the proof of concept was organized according to sub-goals. First, the research aimed at understanding and quantifying the thermal potentials of the 3d printed porous structures; enhancing their capacity for thermal insulation and heat storage. Moreover, the research discovered additional needed properties, specifically issues related to the 3D printing process, such as flow resistance, water tightness, structural robustness and printing time for production. Finally, the research investigates the effects of the façade system in a room environment.

The optimization of thermal performances occurred through an iterative, cyclical process. Several samples with different geometric configurations of porous structures were designed and tested to maximize thermal insulation, allow appropriate heat absorption in the liquids, minimize the flow resistance, achieve acceptable water tightness and minimize the production time. In order to design the test-samples, preliminary choices were made by taking into account that the porosity of the material determines the thermal resistance of the façade. The higher the porosity, the less solid (and conductive) material there is, and therefore higher thermal resistance. Thus, the first set of samples was based on ordered cellular structures like polyhedral, which performed well for thermal criteria and structural robustness, but caused challenges regarding the printing process. To reduce the time required for the printing process and the risk of possible failures during production, the size of the cells was then scaled in all directions except the ones related to the heat transfer perpendicular to the facade. The size of the insulating cavities in that direction was constrained to 15 mm to prevent internal convection since this would cause the thermal resistance to be reduced. As such, the geometry was adjusted to create smoothly curved cavities that remain 15 mm only in the direction of the heat transfer but are larger in the other two directions. This adjustment showed positive results not only reducing the printing time, but also to creating a stiff, yet lightweight structure. Moreover, the smoothness of the geometry allowed for a more stable printing process.

The external layer (where the liquid flows) requires water-tightness and a fluid shape of the channels to allow for minimal pressure drop and uniform flow. Several samples with different configurations were tested for flow resistance and the best performing shape was selected. The current shape of the channels is inspired by natural configurations that transfer fluids such as blood vessels, the veins of leaves and three dimensional bionic structures. Though further investigation is needed, the current shape is promising with regards to the circulation of the liquid. The channels should also allow for appropriate heat absorption into the liquid. To accommodate this need, the current models were produced with Fused Deposition Modelling (FDM) printing, using PETG, a transparent 3D printing material that has relatively low thermal conductivity. Further investigations may consider the calibrated combination of translucent and dark materials.

To control the movement of the liquid through the overall system, each façade panel consist of two external layers that integrate two reversed pumps for water circulation. The water can be stored in a tank in the center of the panel. In a cooling situation, the liquid is first placed on the inside to absorb internal heat gain and is then pumped to the outside layer to discharge the heat to the cool night sky. In the alternative case, for heating purposes, the liquid is placed outside to absorb any solar heat gain during daytime and is then pumped to the inside to release this heat inside the building. The pumps are also connected with the water tank to store the water inside the tank when necessary.

The structural behavior of the overall system was analyzed by investigating the impact of the wind load to the façade panel and calculating the deformations. The result is a curtain wall system that transfers the loads to the main structure of the building. The structural analysis did not reveal major structural challenges. However, deeper studies on the structural behavior of the 3D printed material are required especially when considering extreme thermal conditions and durability.



Finally, the thermal impact of the overall system on a room was simulated. The investigation focused on two scenarios, a summer day and a sunny winter day. Energy simulations showed that a cooling rate of 25 W/m2 could be obtained during typical summer conditions. This is more or less equivalent to 50% of the internal heat gains in a conventional office environment. Similarly, 4.8 kWh of thermal energy could be harvested for a typical 12 m2 office space on a sunny winter day, which accounts for approximately 70% of the typical corresponding heating demand.

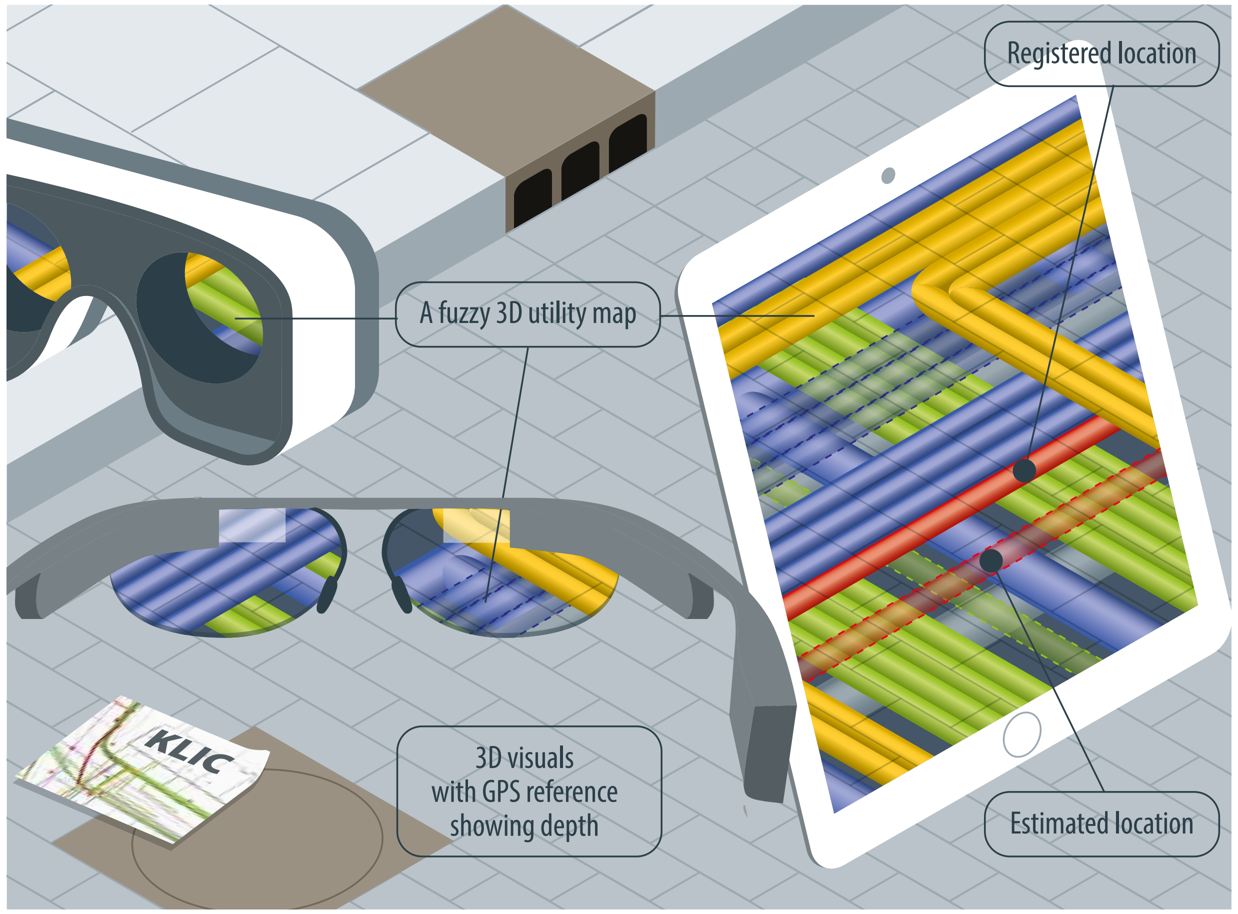
A large 1:1 (full scale) prototype was produced. One important aspect of this research was to study the feasibility to produce a façade panel within time constraints. This was one of the main challenges that influenced the design and the production process. The design process prioritized configurations that have low printing time and specific settings were applied to ensure a speedy printing process. The production process occurred in collaboration with KIWI Solutions. The investigation of the 3D printing technology was based on the latest available production technologies, using 3D printers for larger objects and innovative materials.

In conclusion, the main outlook of this research is a proof of concept for a façade system that can adapt its thermal behavior to different environmental conditions, regulate the temperature inside the building and reduce the environmental impact through innovative production technologies. Despite the challenges faced so far, the project showed promising results regarding the development of tailored products with complex shapes by using 3D printing technology. In the case of Spong3D, it was possible to successfully generate a façade system with high complexity that achieves high levels of thermal comfort. Additionally, by using 3D printing technology the project uses material resources more strategically and minimalizes waste material throughout the production process.

Delft University of Technology
ing. **Maria Valentini Sarakinioti** MSc.,
dr.MArch. **Michela Turrin**,
MArch. **M. Teeling**, ir. **Paul de Ruiter**,
Mark van Erk,
dr.ir.arch. **Martin Tenpierik**,
dr.ing. **Thaleia Konstantinou** MSc.,
prof.Dr.-Ing. **Ulrich Knaack**

Eindhoven University of Technology
ir. **Arno Pronk**,
prof.Dr.-Ing. **Patrick Teuffel**,
Arthur van Lier, **Rens Vorstermans**,
Eline Dolkemade, **Marie de Klijn** MSc.,
ir. **Roel Loonen**, prof.dr.ir. **Jan Hensen**

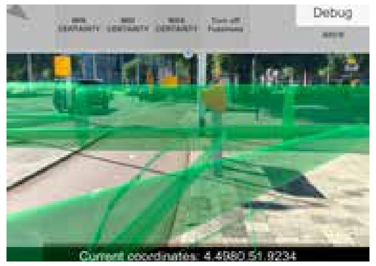
KIWI Solutions
Dick Vlasblom

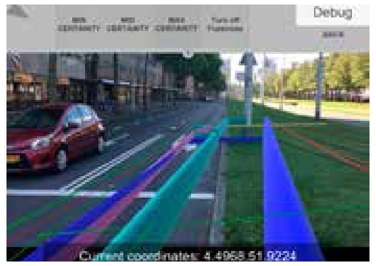


SPYING THE UNDERGROUND

Spying the Underground refers to the buried utilities that are often hidden from the eyes of citizens and city engineers. Since they are difficult to localize and measure from street level, utility plans are the only models that convey geometry information about them. Nowadays, Augmented Reality (AR) techniques allow us to display three-dimensional (3D) virtual utility models over a surface level camera image. To achieve this, 3D information needs to be added to existing utility models. Therefore, we developed a data model that allows storage of depth and geometry information. Based on this, we developed a fuzzy model that will visualize a fuzzy shape that indicates the uncertainty related to the location of each utility. We developed all this while generating 3D models for subsurface utilities at Oostplein Rotterdam.

Three-dimensional utility infrastructure models enrich the spatial view on the subsurface and support the design, construction, and maintenance of networks. Although some geographical information systems (GIS) can store utility data in 3D, most existing utility plans are currently composed of 2D schematic lines. One reason for this is the absence of and uncertainty in available depth information of utility networks. With the use of limited additional location information, it is possible to already move 2D utility plans toward more accurate 3D models. This project, therefore, developed a 3D utility data model that uses various sources of available data to visualize location uncertainties. The resulting 'fuzzy 3D utility model' concept was tested in the field by implementing it in an Augmented Reality (AR) application.





University of Twente
dr.ir. **Léon olde Scholtenhuis**

Delft University of Technology
Dr.-Ing. **Sisi Zlatanova**,
Xander den Duijn BSc,
Anna-Maria Ntarladima MSc.,
Evangelos Theocharous MSc.,

Municipality of Rotterdam

Recognize

For the proof of concept for our fuzzy 3D utility model, we analyzed the distinctive ways that are used in practice to store depth information. We consulted the people responsible for maintenance of the Rotterdam buried subsurface utilities, and we analyzed practical design guidelines such as the 'Rotterdam Handboek Leidingen'. As a next step, we developed a conceptual model to describe subsurface utilities. We, therefore, extended an existing conceptual city model called CityGML Utility ADE. Software developer Recognize then helped us to implement this model in AR. This application was used to visualize the utility data of the Oostplein square in Rotterdam.

The developed model describes a utility network by using concepts such as network features and elements. The features describe, for example, information about the quality of location data. In turn, quality can capture location data by using attributes such as standard, estimated, and measured location. The values and reliability of the location attributes differ since 3D object locations are dynamic; i.e. they change over time when soil settles and cables move. Experts indicated that the registered location has a 5cm accuracy if a utility line is installed recently. Nevertheless, in some parts of Rotterdam, the ground may sink up to 1 cm annually. Such movement patterns are hard to generalize since soil conditions differ spatially. Experts judged that estimated locations can deviate from the real locations around 50 cm to 100 cm in all directions. In the prototype, we visualized these uncertainties by using a minimum, medium and maximum sized cylinder shape that enclosed the standard pipe geometry.

The existing version of the AR-application shows that fuzzy 3D models can be used to convey uncertainty information in utility maps. Three main technical hiccups need to be addressed in future research to further extend this application. First, the actual positioning of the AR-device is important to properly visualize the utility locations. Future research can explore how alternatives to GPS (e.g. LIDAR) can help to position the device more accurately in urban canyons where GPS signal is weak. Regarding the visualization of depth in AR, we also found that it most difficult to show the depth of a virtual object compared to a real-life image on the screen. Our current solution, using a scale symbol to indicate distances between pipes and the surface level, seemed not to be visible and clear. The third important step for future research concerns the visualization of the fuzzy shapes around pipe geometries. Currently, this shape is based on a fixed value for each pipe (having either a minimum, medium of maximum size). In future developments, it would be more realistic to let the size of the uncertainty shape be dependent on the reliability and overlap between existing location information about a pipe section.

All in all, this lighthouse project demonstrated a proof of concept for fuzzy 3D utility modeling in AR. The developed algorithm and UML model enabled the fuzzy visualization of three types of depth information (standard, registered, estimated). The first tests on the Oostplein revealed the first use cases and provided fruitful insights into the future development of the tool. Meanwhile, the product generated spin-off since Recognize was able to use the deliverable in projects for two new clients.

SUSTAINABLE LIFE-CYCLE METHOD

The existing infrastructure of a significant number of business parks in The Netherlands and beyond is deteriorated. It is therefore not surprising that many municipalities are stuck with areas that are no longer attractive for businesses and that are more and more vacated. All across the Netherlands large efforts are undertaken to revitalize the infrastructure of business parks.

One important aspect during such revitalization efforts is the need to understand the life-cycle costs of the new infrastructure system. Despite this importance much of the current focus of municipal planners lies on understanding the first cost of a revitalization, while little understanding prevails over the financial and ecological effects of a new infrastructure system in the long run, gaining such an understanding is important, however, as, independent of the success of a system, municipalities have to guarantee the sound functioning of an area's infrastructure even in the case that only a few companies are occupying a specific area.

To support municipalities, the goal of this PDEng project is it to develop a Life Cycle Cost Analysis (LCCA) Tool to support municipal planners with gaining a better understanding of the life-cycle costs of a business park. More specifically, the project will focus on the harbors at the Twente Channel, which will start being managed by a new consortium in an integrated way in the near future.

The Company Context

The harbors from the municipalities Hengelo, Almelo, Enschede, Hof van Twente and Lochem form one of the biggest inland harbors in The Netherlands. This inland harbors are an important component in the region as 'logistic centrum' in Northwest Europe.

To achieve the desire to increase the water transport in the region, seems to be necessary to professionalize the management of the harbors at the Twente canal. Therefore, these five municipalities have expressed the desire to unify in a centralized management method of the physical and nautical tasks.

In January 2014 the five municipalities have approved a development plan, which was to lead to the establishment of a cooperative in the short term. The requirements of the development plan are:

- A cooperation based on a feasible management model,
- A central coordination and management of the basic tasks and accountable to the port managers,
- The uniformity / harmonization of some basic tasks and regulations and,
- To perform centrally the basic tasks.

Based on the above mention points, the Gemeenschappelijk Havenbeheer Twentekanalen (GHT) was created. This company has the responsibility, among others, to manage the infrastructure of the Twente canal. The first steps of the GHT are:

- To setting up the organization,
- To design and implement the basic tasks and,
- To develop the cooperation towards a more independent company.

The mission of the GHT is:

"Through an effective and efficient development of its basic tasks, in a professional and sustainable method, facilitate an optimum accessibility, quality of life and reliability of the inland harbors and the water-related businesses along the Twente Canal"

Amongst others, the GHT is responsible for managing the physical asset and creating the strategic future plans of the channel. From the physical assets point of view, this means that the harbors must be equipped and maintain according to the accessibility and safety required by the users. Therefore, the GHT should ensure the well-maintenance of the quays, quay walls and the soil (bottom) of the harbors. From the strategic point of view, GHT is responsible for the establishment of long-term visions as well as the establishing and monitoring a central budget and accounts.

Under the coordination and management of the port manager are the multi-year programs drawn up. The objective is to ensure proper coordination, timely maintenance of embankments, quay walls and harbor bottoms to ensure effective and efficient implementation of the maintenance and management tasks.

Being GHT a just conformed company, it is essential for them to establish an operational system. Therefore, in order to fulfill their tasks and responsibilities it is important to equip the company with a unified system that manages and controls the ownership and asset maintenance of its different components.

The PDEng Project

Maintenance in the harbor area is currently done only if an emergency presents itself, meaning it has very short term planning horizons. Given the scarcity of economic resources to be invested in the required processes of maintenance, the tasks of allocating and using the resources by asset managers is a real challenge. The short term operational strategy means that the resources have to be available

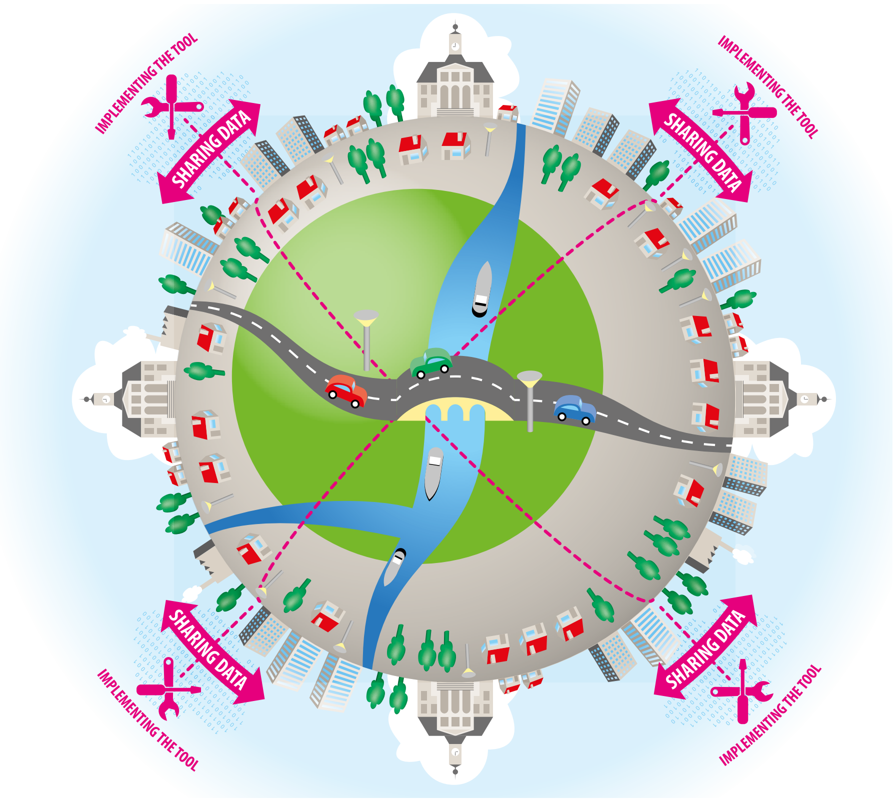
Goal:
Interoperatability

Context information
The municipality gathers the information from the infrastructure above and underground of a city. The zeros and ones represent the "data" of an asset in the database.

The problem
The unawareness of the potential business and common goals a municipality can have with other organization by being in an invisible capsule that block them from this to happen.

The solution
The solution is sharing information. It doesn't have to be all the information the organisation posseses, but only the nesccesary by implementing the tool.

The tool
The database and the Life-cycle cost (LCC) will throw information to qualify performance, resources and interoperability making them work together smoothly.

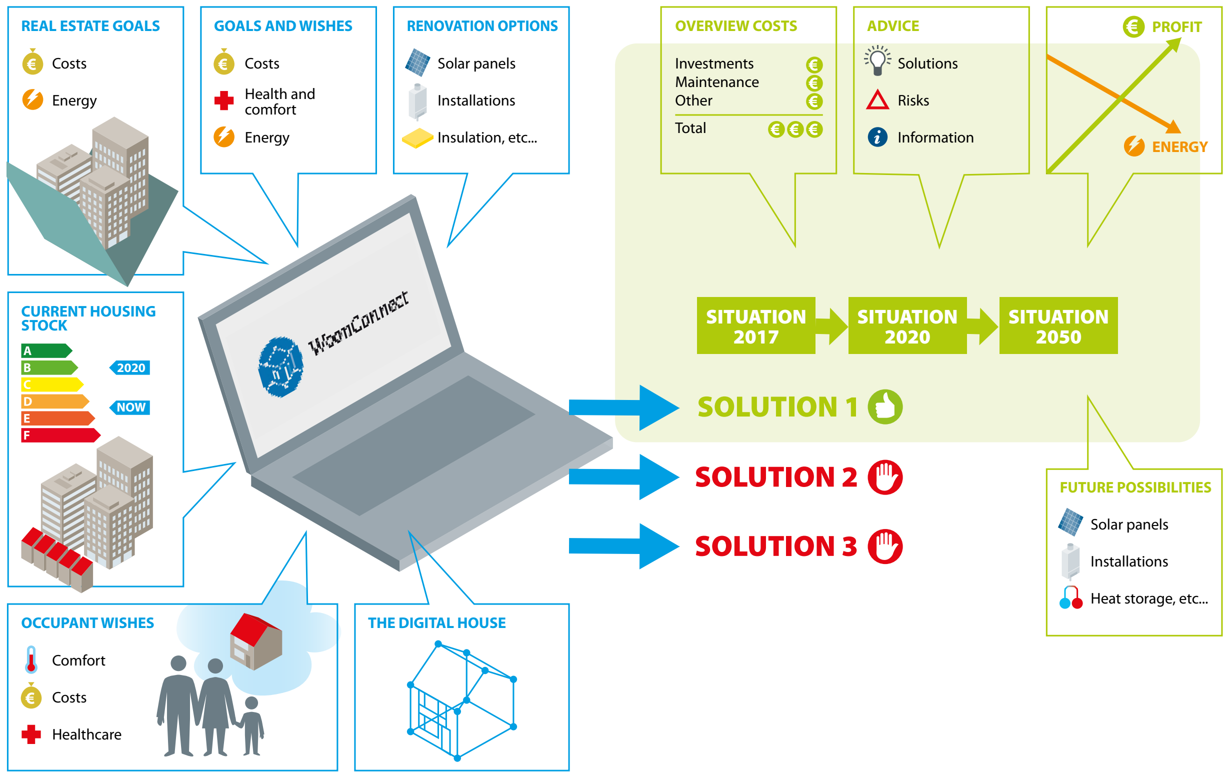


at the moment they are needed. To be able to react quickly to such scenarios, the asset manager need to have at hand the right and current information about ownership, assets present, their conditions and their capacities. However, their current systems do not support the asset manager in obtaining this information efficiently nor consistently, as asset data is not interconnected nor standardized for the whole Twente Channel.

Therefore, the general objective of this project is to create a LCCA Tool to support GHT in deciding on how to allocate efficiently and effectively resources for managing the harbors infrastructure. The LCCA Tool that is being developed in this project allows planners to determine the sensitivity that asset management variables (e.g. preventive maintenance intervals) have on the costs of those asset such that they are supported in designing appropriate resource allocation strategies. Furthermore, it also enables planners in calculating the cost implications of different long and short term scenarios, and by doing so, determine the most efficient way to allocate resources. As Figure 2 shows, the tool integrates a database, a LCCA method and a decision-making engine based on the asset management requirements of GHT. The database allows incorporating a proper classification of the assets, and in combination with the LCCA method, it allows overlapping the life-cycle cost of each one of the assets at harbor. This allows asset managers to obtain tailored information for making construction and acquisition decisions, renewal and rehabilitation activities, and replacement and disposals tasks.

University of Twente
Diruij Dugarte Manoukian MSc.,
prof.dr.ir. **André Dorée**,
prof.dr. **Timo Hartmann**,
dr. **Irina Stipanovic**

Gemeenschappelijk Havenbeheer Twentekanalen



SUSTAINABLE PERFORMANCE OPTIMIZATION

With natural resources depleting, sustainable solutions are becoming more and more a necessity. To deal with the depleting resources, the Dutch government aims to generate 14% of country's energy consumption through natural resources by 2020. The Dutch built environment is estimated to be responsible for 38.1% of the total energy consumption. This means that investments and innovation within this area have high potential.

However, there are some indications that these goals cannot be met. New houses often meet these requirements but, with a growth of 0.8% per year, these only make up for a small portion of all projects. As a result, a strong focus lays on improving and renovating the existing housing market towards a sustainable and low energy environment. For this transition, information on the current housing market, possible renovation options and insight on the investments costs are required.

Within this PDEng-project the aim is to further develop WoonConnect, a digital tool that can help to speed up this transition for both renovation projects and new buildings.

Eindhoven University of Technology
ir. **Randy van Eck**,
prof.dr.ir. **Bauke de Vries**

De Twee Snoeken
ir. **A. Wijnen**, ir. **K. Nix**,
ir. **J. van den Heuvel**

Expanding WoonConnect

To further develop this tool the aim is to integrate the following aspects within WoonConnect:

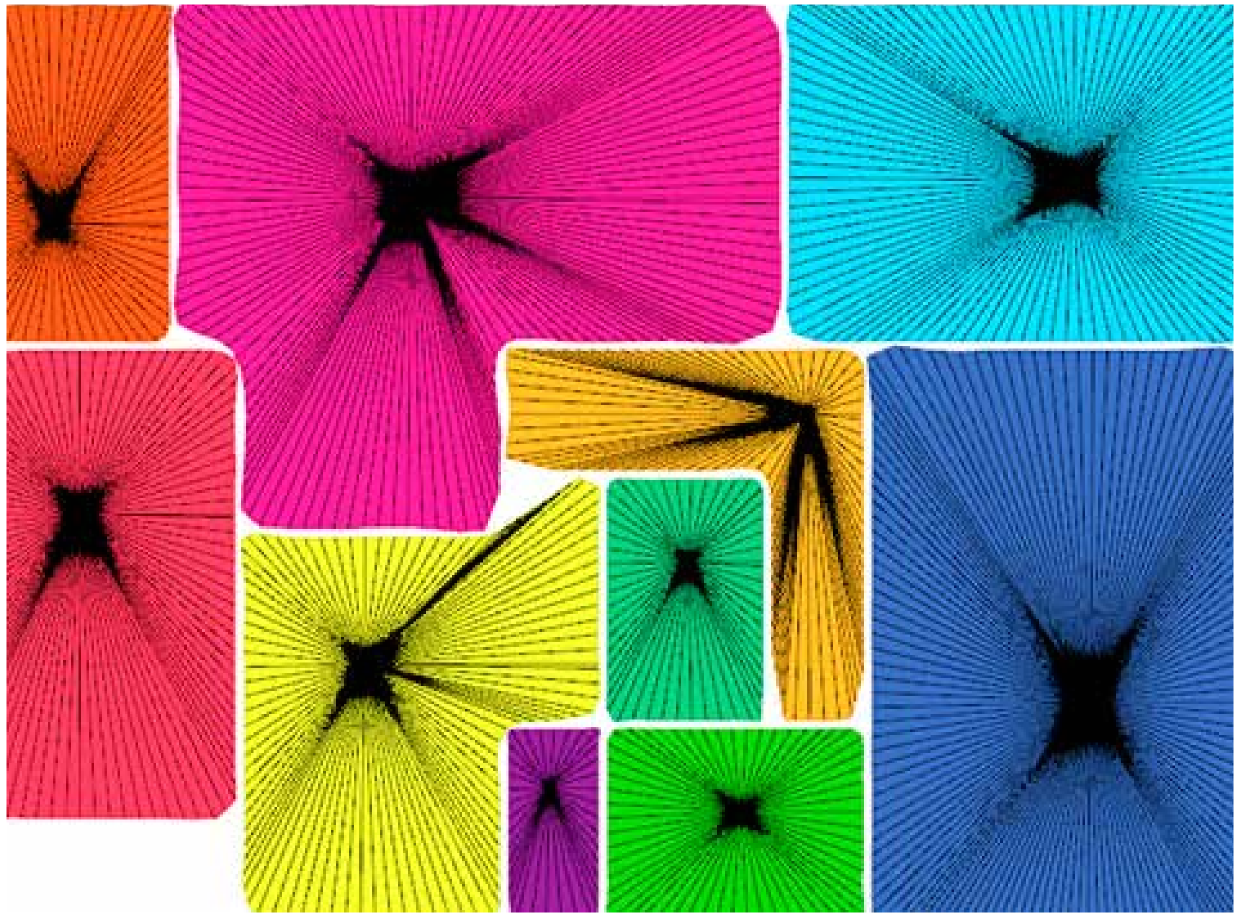
- The software should able to display how the existing building performances in terms of different (sustainable) criteria. The tool should do this in a way that it provides relevant information for the users.
- The software should able to display the (maximum) potential of the building. The tool should indicate in what areas the performances of the building can still be improved. Furthermore the tool should display what investments the user can still make and how it effects the performances of the building with regards to different criteria.
- The software is able to take into account the goals and wishes set by the users. For example, if goal is to develop a building with an energy label of at least label A, the tool should check if the design meets these requirements. Furthermore the tool should also display what the investment costs are to reach this goal.

Approach

WoonConnect in the current state uses BIM-software, a digital building component database (BouwConnect) and the input from onsite observations and drawings to create a digital house. Based on this digital house WoonConnect can already calculate several criteria and compare them to building regulations. Within the tool people can already adjust these digital houses with different renovation options. These renovation options are mapped by de Twee Snoeken in cooperation with the users. These users range from housing corporations, government, real estate groups and project developers. The residents can also use the tool to indicate what type of renovations they find important and to get more information about the project, planning and costs.

To expand WoonConnect we first aim to add additional calculation methods to assess multiple criteria (e.g. CO2-emmisions, material consumption or comfort). Within WoonConnect self an interface will be added in which the outcome of these criteria and the investment costs will be displayed for the different types of users. This interface should be able to provide advice both for now, for long term investments and will help people to express what they find important in their dwelling. In the background calculations will be added that combine different building components that can look for scenarios that meet these wishes. Sensitivity calculations aim to give the users an indication about which building components will influence the performances of the building the most. In the end the model should summarize these calculations within a (printable) interface.

To expand this software we first performed a study about the different criteria, (sustainable) assessment tools and buildings concepts that exist on the Dutch building market. Within this study we also focused on further developing the system requirements. In the second stage interviews were held with different types of users. These interviews are used to understand what criteria are interesting for which users but these also help to understand how these users would interact with the software. The outcome of these two studies will be used to design the interface for WoonConnect. The second part of this project aims to implement cost-performance effective solutions, optimization techniques and sensitivities analyses. These calculation can take into account the different building components, the available budget and the wishes of the users and look for scenarios that meet the different requirements. For the last part we aim to test the interface, if possible, within a case study.

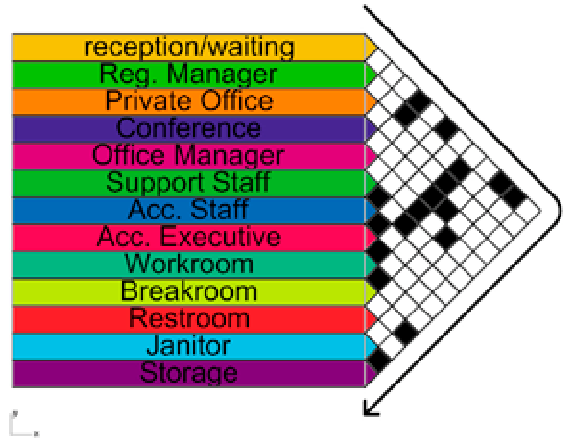


SYNTACTIC AND/OR CONFIGRAPHIC

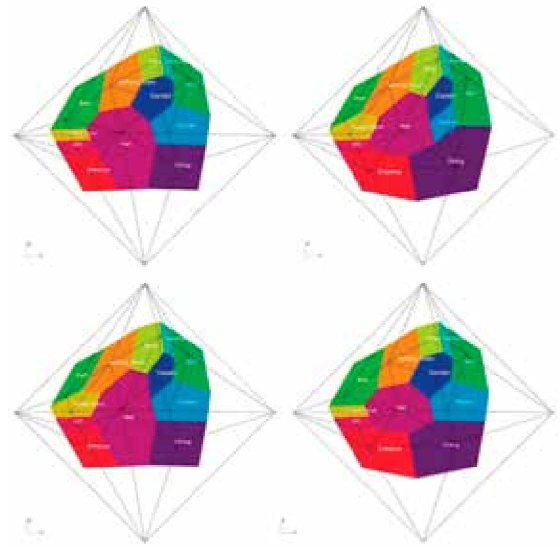
SYNTACTIC is a computational tool suite providing methods for Space Planning, Spatial Layout and Spatial Network Analysis for architectural design. The tool suite allows designers to model complex spatial adjacency and/or connectivity requirements within buildings and analyze their network effects on the functional efficiency and social interaction potentials of a building.

SYNTACTIC provides:

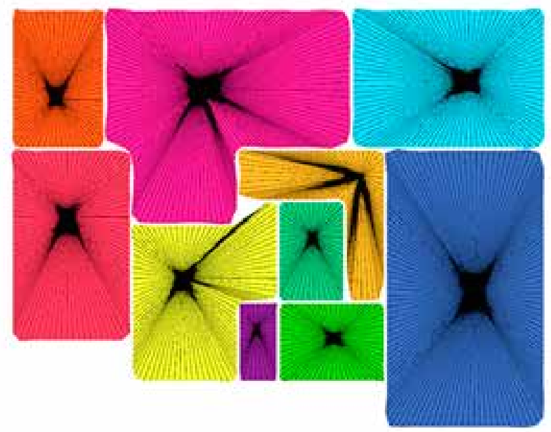
- Interactive bubble diagrams and adjacency tables to quickly construct a Spatial Network Model of rooms/spaces;
- A package of Spatial Network Analysis methods (Space Syntax and alternative methods) to quickly check the potentials of the spatial network as to functional efficiency and social interaction possibilities;
- A set of 2D & 3D Topological/Geometrical Layout tools (WIP) to fit a configuration into a 2D/3D plan boundary.



An adjacency table where a designer specifies desirable connections between spaces within a building.



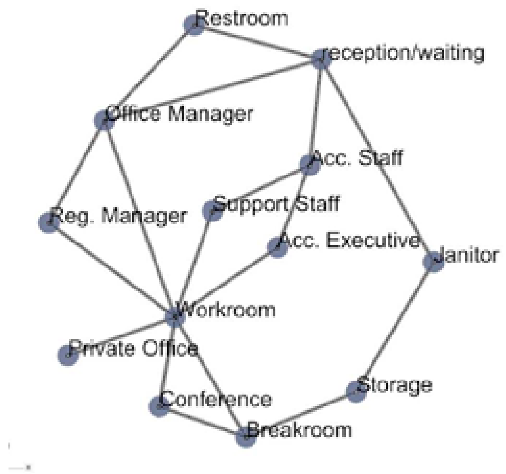
An Isovist 2D bubble agents (bubbles that have a core area from which the entire space is visible) to be used in agent-based modelling of 2D layouts



A generated 2D layout (rectilinear or freeform) with isovist bubble agents.

Delft University of Technology
Pirouz Nourian,
prof.dr.ir. **Sevil Sariyildiz,**
dr.ir. **Frank van der Hoeven**

123 DV Rotterdam
Samaneh Rezvani



A spatial network of rooms which a designer draws as an input for layout and analysis processes.

TERRA-INK

In recent years, natural disaster and military conflicts forced vast numbers of people to flee their home countries, contributing to the migration crisis we are facing today. According to the UNHCR, the number of forcibly displaced people worldwide reached the highest level since World War II. Post-disaster housing is by nature diverse and dynamic, having to satisfy unique socio-cultural and economical requirements. Currently, however, housing emergencies are tackled inefficiently. Post-disaster housing strategies are characterized by a high economic impact and waste production, and a low adaptability to location-based needs. As an outcome, low quality temporary shelters are provided, which often exceed by far their serving time. Focusing on temporary shelters suitable for the transitioning period between emergency accommodation and permanent housing, TERRA-ink addresses new construction methods that allow for time and cost efficiency, but also for flexibility to adapt to different contexts.

TERRA-ink aims to develop a method for layering local soil, by implementing 3D printing technologies. With the aid of such a construction system, the goal is to create durable structures that can be easily de-constructed once they served their purpose. The use of locally sourced materials in combination with additive manufacturing is investigated aiming at reductions in financial investments, resources and human labor, as well as at simplified logistics, low environmental impact and adaptability to different situations and requirements. Such a building system has the potential of combining low- and high-tech technologies, in order to facilitate a fully open and universal solution for large scale 3D-printing using any type of soil.

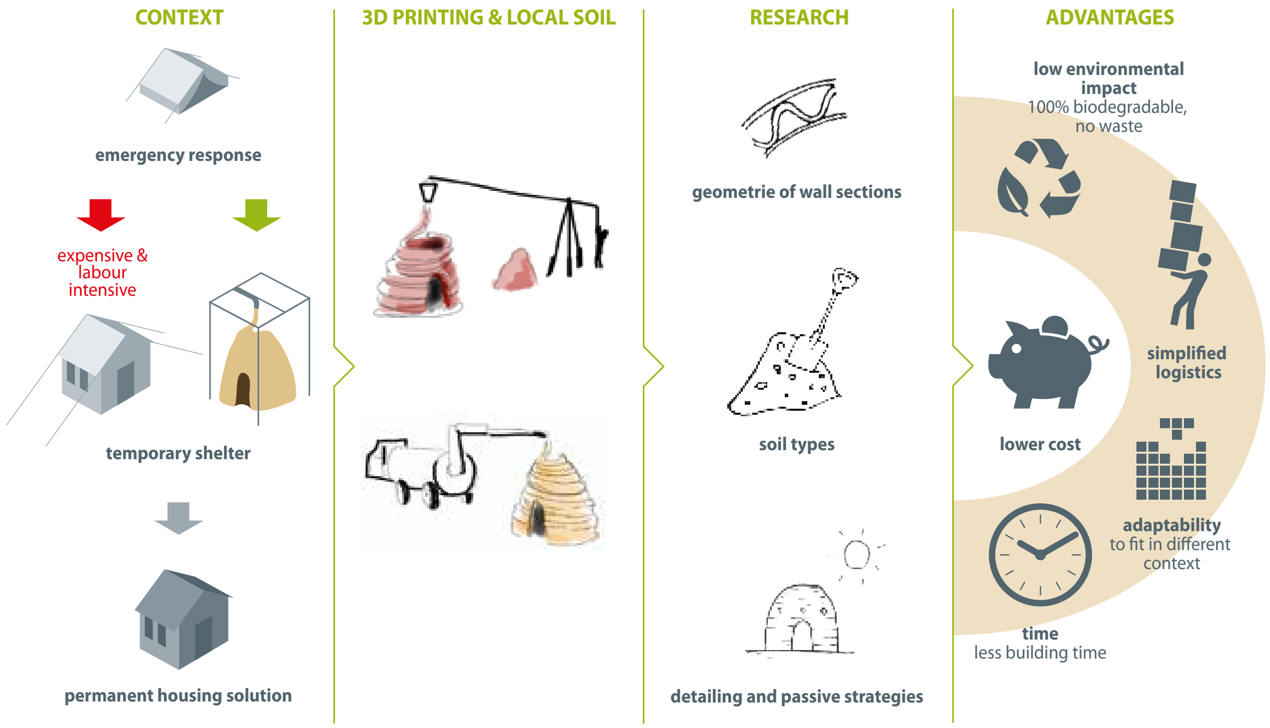
Preliminary studies were conducted to explore the potential for innovation in an emergency relief process. In practice, an emergency response is usually organized and divided in separate phases. Each phase addresses different problems and needs. A temporary shelter is meant to respond to an intermediate phase of the emergency, to facilitate the transition from emergency accommodations to more durable housing solutions. Therefore, a temporary shelter can be defined as a dynamic process more than a final product; a solution adaptable over time and easy to deploy and dismantle.

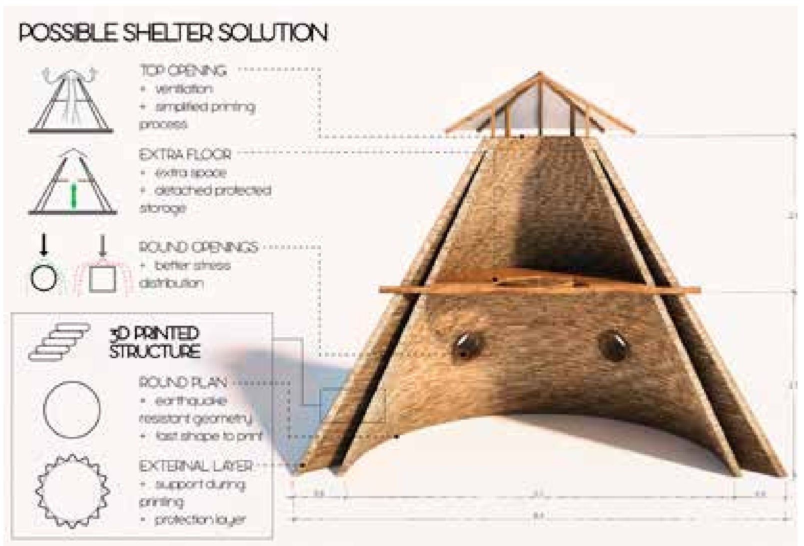
Aiming to increase the flexibility and adaptability of the process, the project examined the potential of a construction system based on the deposition of soil material, without relying on a specific technology or material recipe, but rather adjusting to the available resources. During the project, the use of both local materials and generic machineries was investigated. Soil material was studied focusing on the material properties of various mixtures in dry and wet conditions. Different mixtures (clay + aggregates) were considered, in order to define how various clay types and grain size affect the physical and mechanical properties of the material. Then, compression tests were conducted on dried soil samples. The results were used to define the compressive strength and other parameters for the structural analysis. The influence of additives and different kind of natural fibers (ex. straw, jute and hay) was confirmed to be an important aspect in the design of the mixture, as the fibers in the mix increase the tension resistance of the soil and reduce the shrinkage.

Besides studying the mechanical performance of dried soil, the project investigated the properties of the mixture when in fluid state. Its behavior was analyzed during the extrusion process used to deposit the material in layers. Parallel to the material studies, the project focused also on the hardware developments, since it also affects the extrusion process. More specifically, commonly available machineries are utilized in this project, in order to explore an alternative open-source solution for large scale 3d-printing that can be applied in all emergence situations. This approach offers simplified logistics and reduced costs, especially when compared with existing technologies such as robots or big commercial printers. An industrial clay pug-mill and a concrete mixer were tested to define the characteristics that allow a good extrusion of the material. By studying the interaction of the machines with the liquid soil mixture and its deposition, it was possible to define and highlight the main parameters that influence the correct design of a soil mix. The criteria of the extrusion quality are based on (1) material coherence and (2) extrusion speed rate. In particular, the material recipe had to be adjusted to achieve a more liquid mix to meet those 2 criteria. A good design of the mixture for 3dprinting application must achieve an appropriate balance between a smooth extrusion flow and control of deformation during the drying process.

Additionally, investigations were made on the design options, regarding the geometric configurations and structural behavior of the shelters. As a test case, a simple shelter design was analyzed to identify solutions using as little material as possible (simultaneously reducing the printing-time), but still achieving good structural stability.

Since curved shapes are generally faster to produce by 3D-printing, a simple round-shaped solution in plan was examined first. Compared to other geometries, round shapes offer also the additional benefits of being earthquake-resistant due to their symmetry in all directions. After defining the boundary conditions (such as maximum dimensions of printing area and structural properties, based on laboratory tests and literature) structural optimization was used to identify the optimum geometries. Due to uncertainties in the behavior of the printed material, the results are preliminary. Nevertheless, they indicated domes and cones as the most efficient shapes, minimizing tension stresses where soil is more vulnerable. Using simulations in a structural analysis software (Karamba in Grasshopper for Rhinoceros, McNeel), irregularities in the wall surfaces (such as openings) were examined in order to identify the limitations in dimensions and the best geometries for doors and





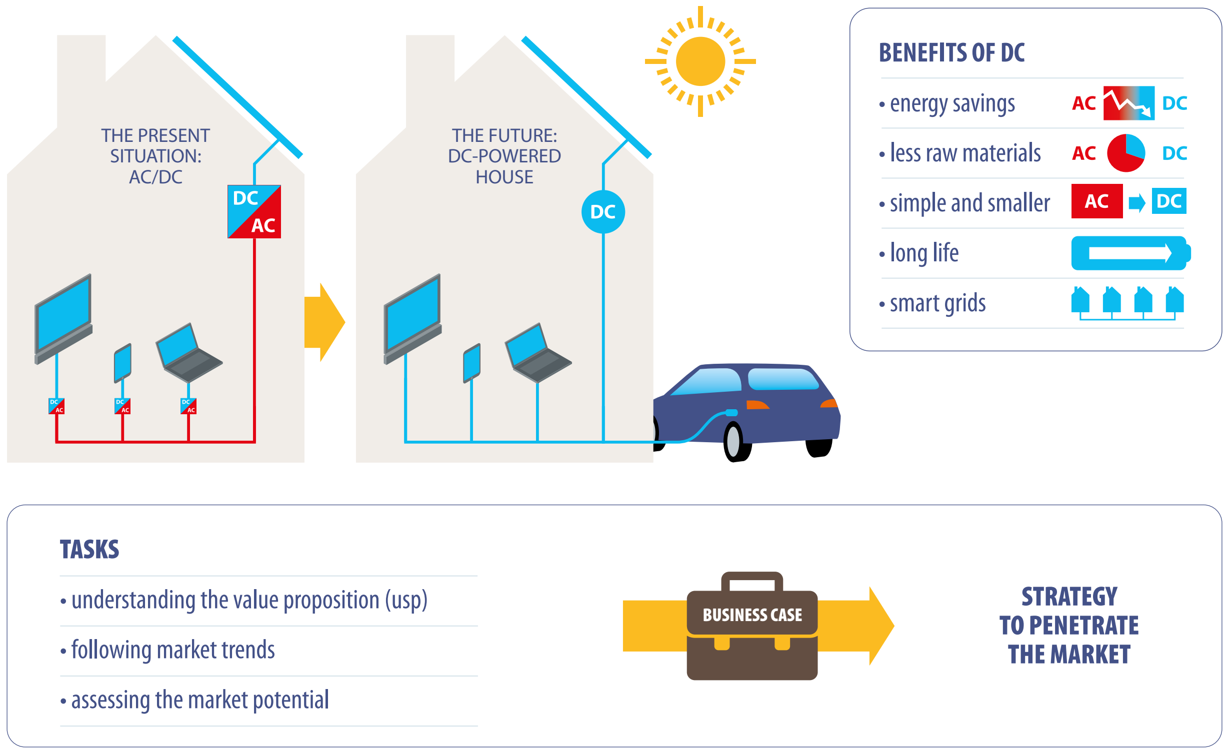
windows. Using 1:1 scale printed samples, on-going tests aim at determining which geometries can be actually produced. In fact, the shape and geometries of the shelter are also a consequence of the printing process. During the deposition, the liquid material tends to deform and eventually settle under its own weight. When occurring in rather uncontrolled environments (such as on-site, where shelters are needed) the impact of this process can be high. The lack of stiffness and stability of the layer can be counteracted by its geometry. A flower shape layer deposition can drastically improve the stability of the overall structure, until the mixture is dry enough to withstand its own weight. For this purpose, a second external layer is printed in order to give extra support during the extrusion process and contribute to redistribute the stresses once the wall is dry. This external layer is also a useful protection against atmospheric conditions. The inner gap could provide benefits in terms of ventilation or can be filled with insulation material, depending on the local climate.

During the process, several small-scale tests were made. A 1:1 scale prototype of a wall portion is being realized as a proof of concept. The prototype will be used also to further test the geometries and the structural performances.

Though more research is necessary to develop the construction system, the current results show its potential of applicability. This direction indicates the plausibility for a significant change and improvement in the emergency relief field. Some of these potentials can be significant also beyond the case of emergency architecture. Besides that, the further benefits of soil as a building material are highlighted. Over the past centuries, soil was always used; but nowadays it is often underestimated or associated to modest constructions. Today, in combination with innovative technologies, it could be reconsidered and regain its relevance.

Delft University of Technology
Tommaso Venturi,
dr. **Michela Turrin** MSc Arch,
Foteini Setaki Msc Arch,
dr.ir. **Fred Veer**

Eindhoven University of Technology
ir. **Arno Pronk**,
prof.Dr.-Ing **Patrick Teuffel**,
Yaron Moonen, Stefan Slangen, Rens Vorstermans



TRANSITIONS TOWARDS MICRO DC GRIDS

Our electricity is predominantly powered by alternating current (AC), ever since the War of Currents ended in the favor of Nicola Tesla at the end of the 19th century. However, lots of the appliances we use, such as electronics and lights with light-emitting diode (LED) technology, work internally on direct current (DC) and it is projected that the number of these appliances will increase in the near future. Another contributor to the increase in DC consumption is the ongoing electrification of mobility (Electric Vehicles (EVs)). At the same time, photovoltaics (PV) generate DC voltages, while the most common storage technologies also use DC. In order to integrate all these appliances and technologies to the existing AC grid, there is a need for converters which introduce power losses. By distributing DC power to DC devices instead of converting it to AC first, it is possible to avoid substantial energy losses that occur every time electricity is converted.

This situation initiated the concept for the implementation of the DC-Flexhouse project. A prototype DC installation will be developed and tested in one of the buildings of the developing living lab area called the District of Tomorrow (De Wijk van Morgen) which is located in Heerlen, the Netherlands. A neighborhood cooperative (Vrieheide cooperatie) is also part of the consortium in order to address the aspect of social acceptance.

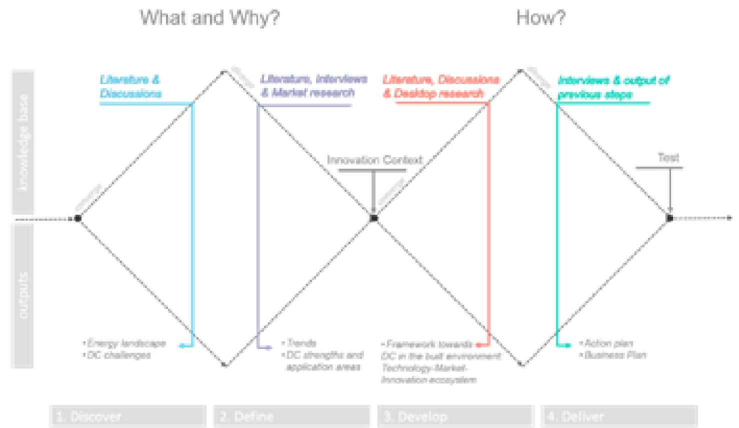


Figure 1. Methodology

Although DC seems to be a promising solution for a more sustainable energy system, the business case is still debatable due to both technology- and market-related challenges. The current energy infrastructure is predominantly based on AC, manufacturers produce devices based on AC standards and people are using many AC products across a long life span.

This Smart Energy Buildings & Cities (SEB&C) PDEng project is a contribution to the DC-Flexhouse project. The aim is to analyze the challenges in the transition to DC micro grids, assess the market potential of DC applications in the built environment and develop a framework that leads to a commercial success.

Project Scope and Objectives

This project targets to support the transition to DC micro grids in the built environment by investigating enabling strategies for successful market introduction, while considering both technology and market aspects. More specifically, the following objectives are identified:

- Assessing the market potential: The market opportunities that arise within the DC innovation are investigated based on trends in the energy sector and relevant industries.
- Proposing a strategy for the transition to DC micro grids: Companies and organizations involved in the DC-Flexhouse project can use this proposition to steer activities towards the commercial realization of DC micro grids. The proposed strategy is intended to be applied not only to DC-Flexhouse project but also to future projects for the development of DC technology.

Methodology

The methodology of this project combines principles grounded in research on innovation and transition management with guidelines from a more practical structured design process. More specifically, the implementation of this project was based on the combination of transition theories, the Multi-level Perspective (MLP) and Transition Management (TM) with the Design Thinking (DT) method. The MLP is used to analyze how transitions towards sustainable energy systems take place and identify how DC innovation can potentially challenge the current energy system, while TM provides guidelines aimed at facilitating and directing processes towards the commercialization of DC. DT offers a step-by-step guideline for developing innovative solutions for complex problems by deliberately incorporating the concerns, interests and values of stakeholders into the design process.

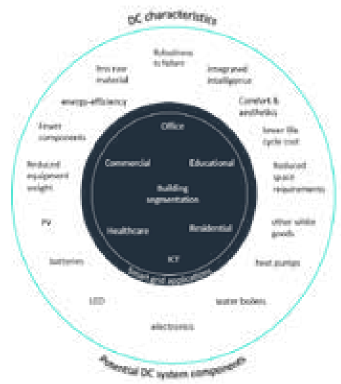


Figure 2. Benefits of DC and potential application areas

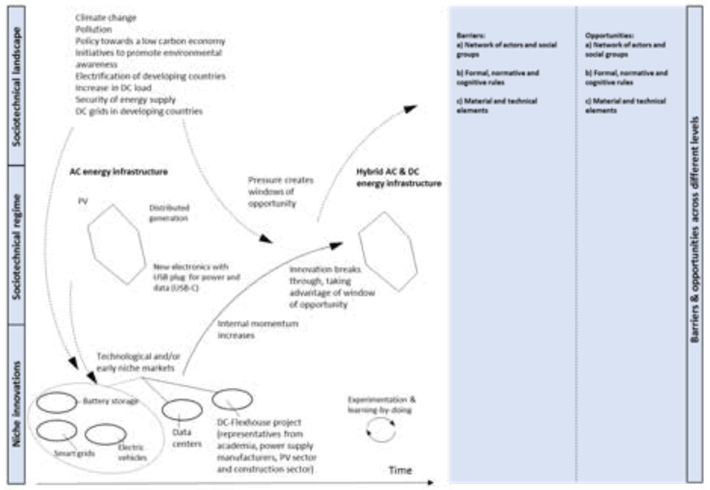


Figure 3. Assessment of the future potential of DC innovation according to the MLP framework (adapted from Geels [1]). The PV market has boomed over the last years mainly due to policy support (net-metering scheme). Battery storage and EVs (DC technologies) are currently niche markets, however the market outlook is positive. Again, policy support is expected to play a significant role. Challenges and opportunities are identified across the different levels and dimensions of the MLP framework. It can be argued that although currently there is no explicit market need for DC applications, DC fits within the overall developments in the energy sector.

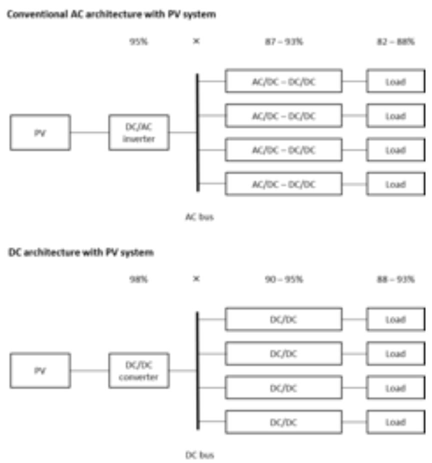


Figure 4. AC versus DC building distribution with PV system and power system conversion efficiencies. The overall efficiency of the power path is the product of the efficiencies of the PV converter and the power converter of loads (Figure 9). Comparing the high efficiency systems in both cases, energy savings with a DC distribution can be around 5%.

Background Information

The prototype in-building DC micro grid that is being designed in the framework of the DC-Flexhouse project will integrate PVs, battery storage and DC loads. The goal is to provide direct DC power to DC loads, thus avoiding the otherwise necessary conversion steps. The key feature of the DC micro grid, however, is that it is a smart grid in itself, meaning that it comes equipped with an energy management system to monitor and manage energy use.

In addition to the benefits of energy savings and potential lower capital costs due to fewer components (elimination of converters), DC offers the advantage of high penetration rate of intelligent hardware thanks to electronic transducer technology. This feature allows smart grid services to be offered to all electricity market players, including the end-users (building owners/users) themselves.

Brief Discussion of Results

DC technology is a radical innovation that requires the transformation of the well-established AC energy system. At the time this PDEng project is conducted, there is no explicit market need for DC applications. Therefore, it appears to be difficult to gauge the market potential at this moment. However, building upon the MLP framework, the trends and drivers that can lead to the breakthrough of the DC innovation were identified.

The wider developments in the energy and building sectors, such as the increasing use of DC loads, growing penetration of PV, expected falling prices of battery storage technologies, potential change in net-metering policy for PV, and regulations for improved energy efficiency of buildings, point at the future market potential. In other words, it can be argued that DC innovation fits within the overall energy transition and can have a big impact if managed properly.

Based on my personal observations during my involvement in the DC-Flexhouse project and principles inferred from the innovation and transition management literature, a set of recommendations towards the commercialization of DC was developed. Following these recommendations increases the likelihood of commercial success in the future.

Parties that want to promote DC technology should first target to build strategic alliances with co-innovators and then find frontrunners that are willing to invest and adopt the innovation. A key co-innovator is grid operators. A financial analysis for residential buildings indicates that an in-building DC installation is an attractive business case for the building owner when the power supply is provided by a DC distribution grid. Therefore, the involvement of grid operators is crucial for the successful commercialization of DC applications.

The frontrunners create the niche markets that facilitate the diffusion of the innovation into the mainstream markets. According to the transition management literature, the transformation of regimes starts from technological niches and/or early niche markets. In the DC case, potential niche markets or early adopters were identified by combining the value proposition of DC with needs and perceived values in different market segments. Potential groups of early adopters are office buildings with high lighting and computing demand, educational buildings and new neighborhoods. Niche markets might initially not generate a substantial level of profit for the actors in the value chain, but entering these niche markets will facilitate broader market development at a later stage.

Deliverables

In line with the project objectives, the key deliverables are:

- An assessment of the market potential of the DC innovation that is grounded on transition management literature
- A case study for residential buildings with a photovoltaic installation based on a cost-benefit analysis
- An action plan for companies and organizations involved in the DC-Flexhouse project towards the commercialization of DC technology
- A business plan for the development and market introduction of DC applications based on future trends and financial projections (pro-forma financial statements)

Conclusions

Overall, this PDEng project demonstrates the future market potential of DC and provides a strategy that paves the way towards a commercial success based on examples of successful breakthrough of other sustainable innovations. Early involvement of actors within the value chain at this stage will help them capitalize on this market potential in the future and generate new revenues from the production of DC products. If the findings of the DC-Flexhouse project validate in practice the current theoretically validated findings for improved energy efficiency, reduced capital costs and robustness to failure, we can expect to see DC installations in the built environment in the near future.

Eindhoven University of Technology
Evi Ploumpidou,
prof.dr. **Sjoerd Romme,**
dr. **Madeleine Gibescu**

ABB BV
Arno Bronswijk

DC Flexhouse

Direct Current BV
Harry Stokman

NEBER
Pepijn van Wiligenburg

EPM BV
Wil Paulus

References

1. F. W. Geels, "The multi-level perspective on sustainability transitions: Responses to seven critisisms," Environmental Innovation and Societal Transitions, vol. 1, no. 1, pp. 24-40, 2011.
2. D. Loorbach, Transition Management: new mode of governance for sustainable development, 2007.
3. M. Geissdoerfer, N. M. Bocken and E. J. Hultink, "Design thinking to enhance the sustainable business modelling process - A workshop based on a value mapping process," Journal of Cleaner Production, vol. 135, pp. 1218-1232, 2016.

THROW IN THE I-DRONE

Although many consider drones to be toys, multiple industries, such as the agriculture and mining industry, already know what advantages professional Unmanned Aerial Vehicles (UAVs) can offer. However, many companies in the construction industry do not seem to be familiar yet with the possible advantages of UAVs for their projects. In our 3TU Lighthouse project "Throw in the I-drone" we, the University of Twente, Delft University of Technology, HeightTech and BeemFlights, would like to make the construction industry aware of the possibilities UAVs have by demonstrating possible usages, by providing a protocol on how to use them and by simplifying the interpretation of data collected. Especially, the use of UAVs with an infrared camera will have our attention, because these systems can help in improving the energy performance of buildings reducing their environmental impact.

The Gap: Mesa Scale Temperature Mapping

Thermography enables us to distinguish surfaces with different temperatures. Temperature data from infrared cameras can, for instance, pinpoint flaws in the thermal shell of buildings or electric problems in the meter cup board. The application of thermography on buildings is already a well-known practice. Unfortunately, this process is tedious and time consuming. On the other hand, large-scale airborne temperature mapping is both applicable and useful to document temperature signatures on the scale of whole suburbs at once. Still, that method is expensive and less controllable. As a result, these micro- and macro-

scale of temperature mapping solutions help specific niches, while the intermediate mesa-scale stays underexplored.

The Challenge: Showing UAVs with IR to the Construction Industry

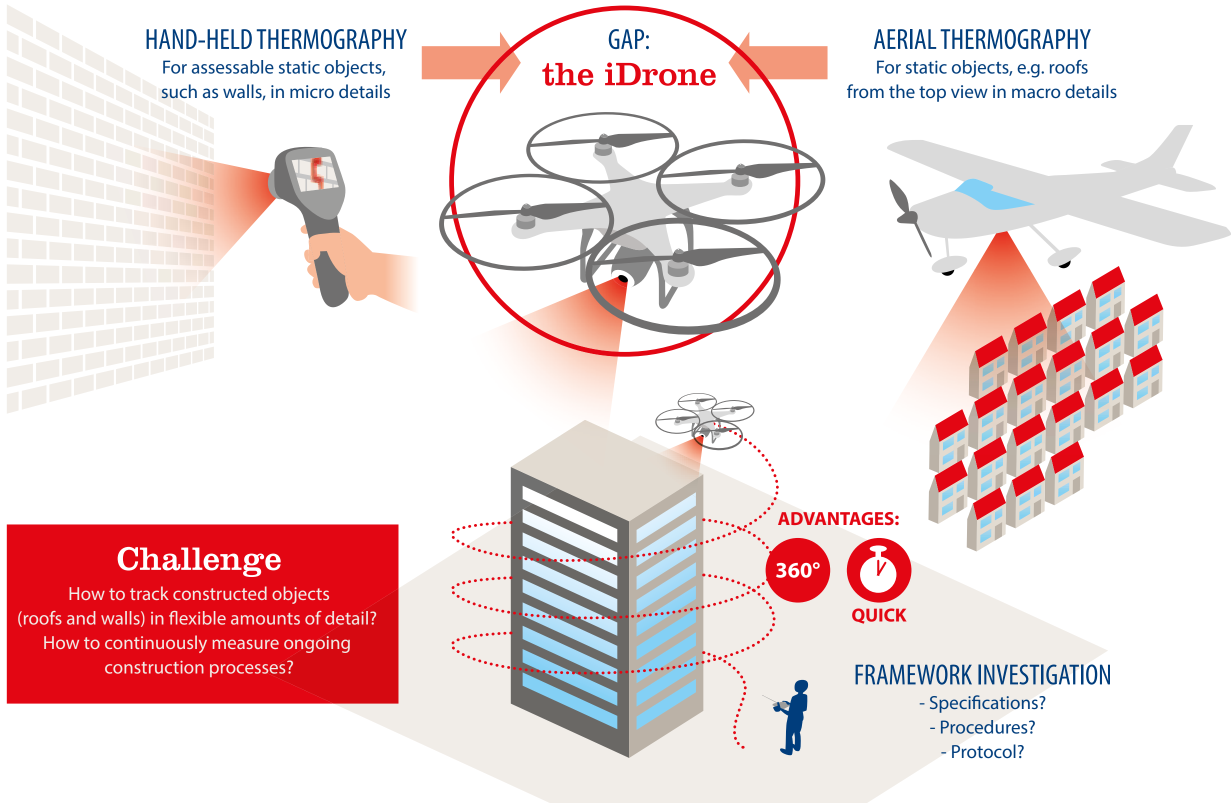
The University of Twente, Delft University of Technology, HeightTech and BeemFlights want to collaboratively challenge the current rules of temperature mapping by exploring this mesa-scale. We target to provide the missing link for the micro to macro temperature mapping continuum. Specifically, we aim to leverage current advances in IR-technologies and remote control Unmanned Aerial Vehicles (UAVs) to fill this gap by utilizing an "i-drone". The versatility of a UAV combined with enhanced IR vision enables new innovative type of temperature mapping, not available on micro and macro level.

This challenge has not widely been taken up by the construction industry, due to the risk of failing to repay the costs of the equipment. We expect it to open new horizons and enrich a number of practices. Among other tasks, the UAV will be very useful in monitoring building processes, studying the thermal losses of roof-systems, malfunctioning photovoltaic panels and for the inspection regarding building regulation. We will test the combination of UAV and IR cameras for constructions in use, e.g. dwellings, industrial buildings, and/or office buildings.

The Results: Research and Knowledge Valorisation

Our first efforts resulted in great footage to support our research and external communication. With the help of an UAV with a conventional camera a teaser was made to show the opportunities drones can offer in the construction industry when equipped with an infrared camera. Meanwhile, it was possible to establish a collaboration with drone manufacturer HeightTech.

Secondly, a literature study by means of a capita selecta by a master student was conducted on thermography, UAVs and the combination of both providing insights in the current fields of knowledge.



Thirdly, as part of a bachelor thesis assignment a questionnaire was composed and interviews were taken among construction companies, facility managers and building advisors to find out what solutions an UAV could offer, enabling us to assess the potential impact of utilizing drones in the construction industry.

More technical elements in our research project, a fourth step, were focusing on how data is being collected by an infrared camera and how photovoltaic systems can be inspected with the help of an infrared camera.

The Future: Testing and Follow-ups

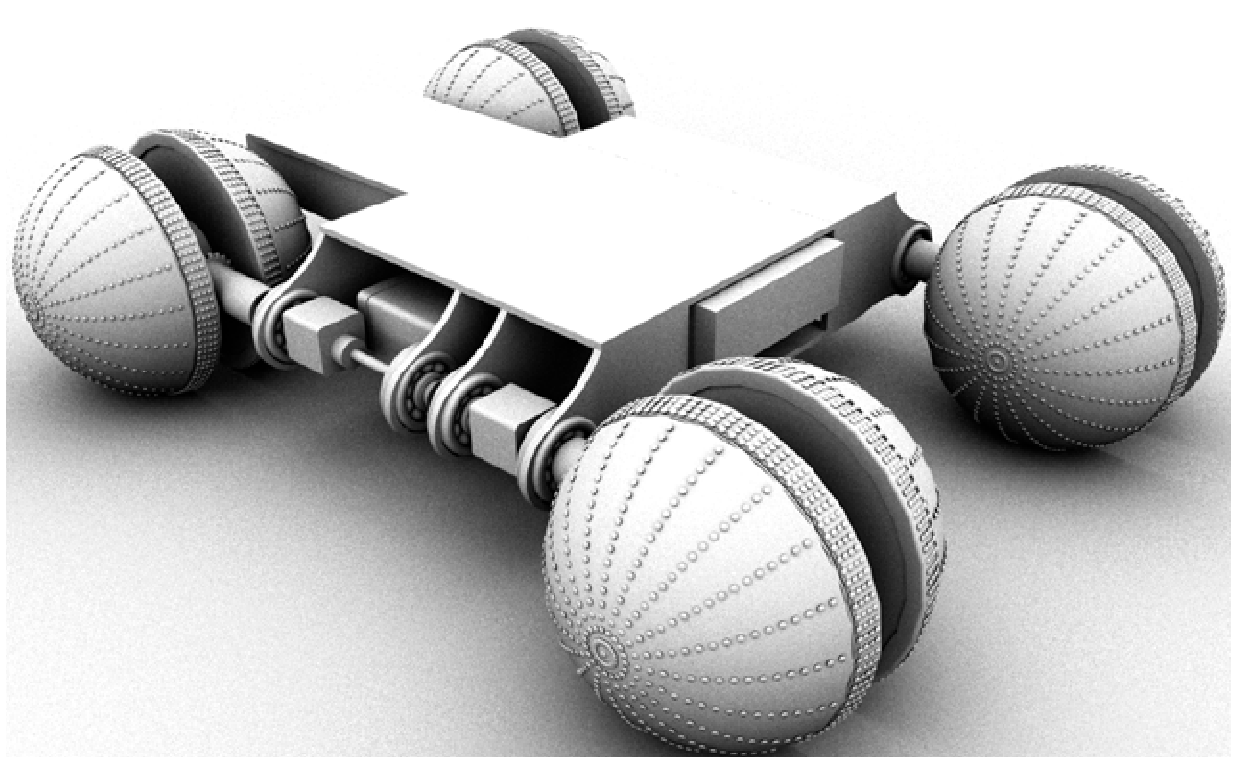
Currently, we are studying how to integrate the data obtained by the UAV and the output of data analysis into standard automated assessment procedures, reducing the amount of time normally needed to select, prepare and analyze the data. We are also developing a flight protocol. We plan to test our protocol for a building in use and a photovoltaic system by the end of February 2016. Last but not least, a follow up of the i-drone project is being discussed with companies in the field. It seems that multiple challenges still need to be overcome, before the construction industry and buildings can benefit from the use of professional UAVs in their full potential. A continuation by means of a PDEng trajectory seems an appropriate next step.

Delft University of Technology
ir. **Eric van den Ham**, dr. **Regina Bokel**

University of Twente
dr.ir. **Bram Entrop**,
dr. **Alexandr Vasenev**

BeemFlights
Sander Mutsaards

Height-Tech Benelux B.V.
Ernst Thijsen



UNLEASH THE BUILDING BOTS

3D printing techniques for the building industry are developing fast. Concepts like Contour printing, concrete printing concepts of the TU/E and D Shape are examples. Despite the range of techniques is broad (and vary from a large gantry system, to a supersized Delta printer for example), many of the developed 3D printing machines are constraint in their movement. Mobile 3D printers however show advantages in flexibility, as they can move outside the constraint of a large 3D printer and they can move in the highly unstructured and hazardous environment of the building site, which can be dangerous for people to work in. The Institute for advanced architecture of Catalonia developed vehicles, which they call minibuilders, each designed for a special task in the building process, printing the foundation, printing a wall, smoothing the outer-wall etc. The minibuilders are used in succession according the building process. However, they are still limited in their autonomy and capability. The minibuilders are tethered with a hose to a vehicle, which carries the concrete supply.

In this research, we will look for the possibility to develop autonomous agent-based robots, which are not constraint in their reach and which have the capability to work together. The robots will decide how and with how many other robots they will do the job. Autonomous robots are robots that can perform desired tasks in unstructured environments without continuous human guidance. Each robot has a list of components, which it can print with the basic material. Together the robots calculate how to solve a 3D print task and how many must/can help. If one robot needs to refuel or needs to get additional printing material, the others distribute the tasks between them so the job will continue. When returning to the building site the robot can choose to join in or perform another task. The robots need to know when to "refuel" and to refill the basic extrusion-material from a centralized point. In summary, each robot must have at least the following capabilities:

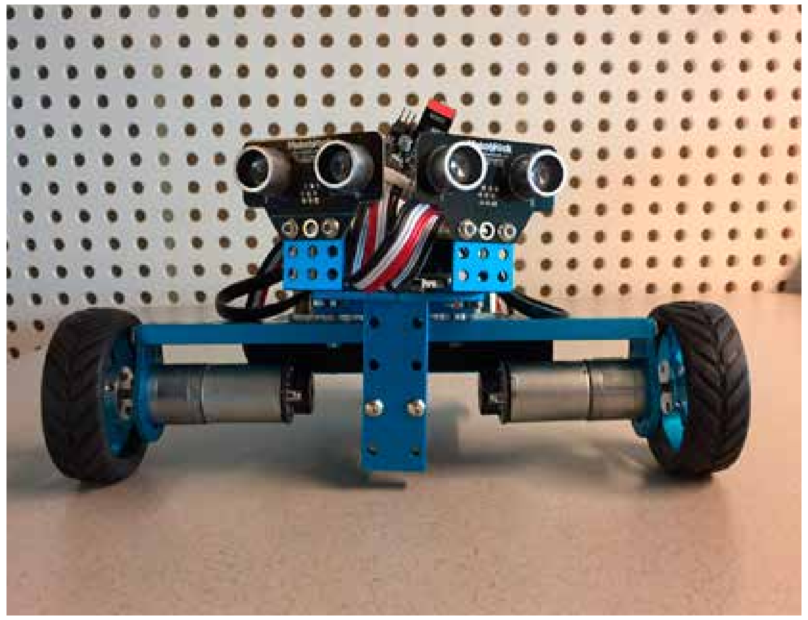
1. Know its location on site
2. Know its exact geo-locate location of the building
3. Know its state
4. Know where its fellow robots are
5. Avoiding obstacles (fellow robots, material and fuel, erected building components)
6. Communicate with fellow robots
7. Extrude simple components (columns, walls)

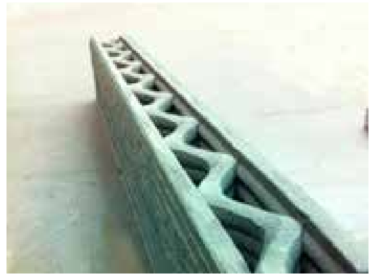
In order to keep the weight of each robot low, it can only carry a limit amount of concrete. So, the extruded walls must be light-weighted. For the project a new type of nozzle was developed, which can print the two side plates and the wall infill in one step. This type of wall has also a higher thermal isolation than solid walls.

A problem that still should be solved is the "climbing". The building bots must be capable of climbing a wall in order to reach the location where it has to print, or climb down a wall in order to go to the hive for refilling its concrete supply.

Each building bot has a microprocessor as it's mind and is connected to the hive by Bluetooth. The microprocessor can be programmed to round obstacles which the building bot will encounter on its path to the hive or work location. It knows its location on the site by calculating its orientation by means of the difference in speed between left and right wheel and by comparing its location to the line between starting point (= hive) and endpoint (= work location).

The building bots can, besides printing, also be programmed to perform other tasks. Therefor a small industrial robotic arm or other tools can replace the printing nozzle. When other tools are mounted on the builderbot, it can perform some simple tasks at, for people, hazardous locations.





Eindhoven University of Technology
Aant van der Zee

Delft University of Technology
Paul de Ruiter

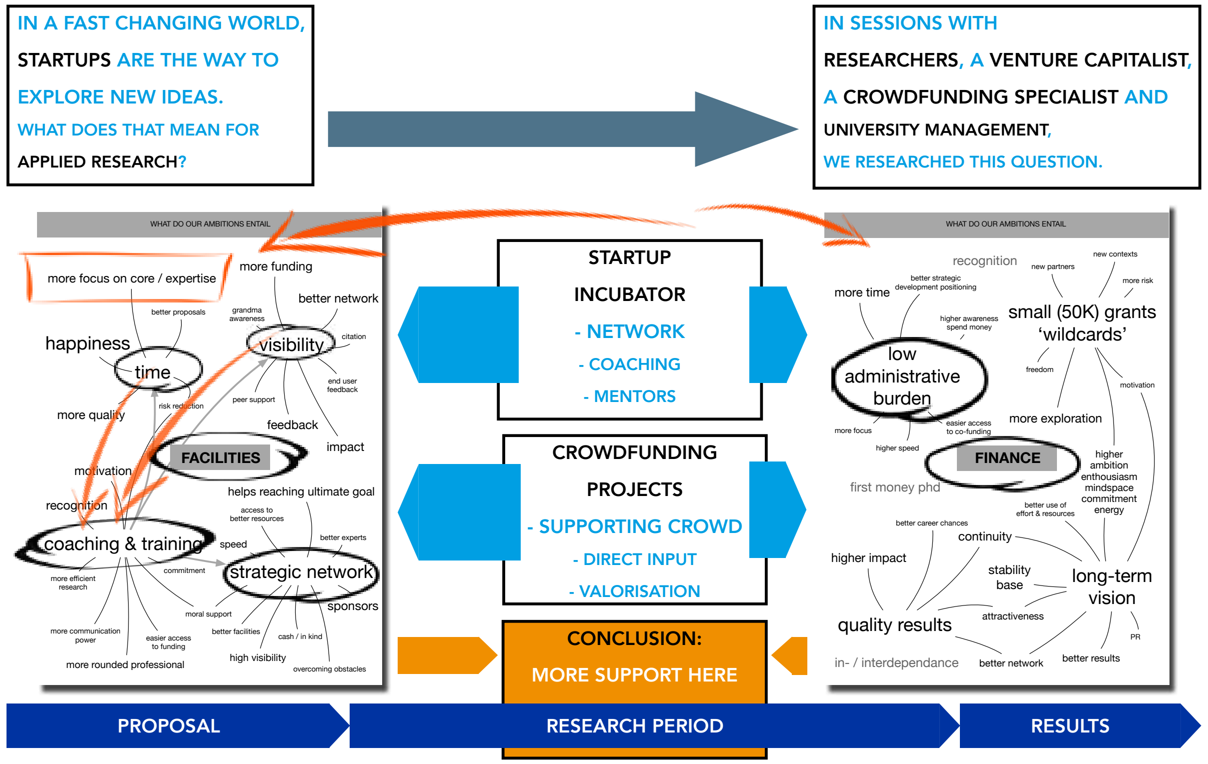
TBI Kennislab
Hayo Meijs

EVENTS
2014 – 2017

Future Formats for Applied Research
Real Additive Manufacturing: Real | Dream
City of Things
Real Additive Manufacturing: Prototype | Production
Research to Reality
City of Realities

Besides the research programmes, various conferences and workshops have been organised in collaboration with specific faculties or like-minded organisations as for example ClickNL, SOUL-FI and KNOB. All these events were tailored to gain knowledge and skills on specific themes, dealing with upcoming new technologies as well as with facilitating topics as finance and process formats.

These events were accessible for research staff members and students, as well as for representatives from industry and (local) government from the domain of the built environment and specifically also for interested parties from other disciplines. Thus enlarging the opportunities for sometimes unnerving self-refection and unexpected knowledge exchange.

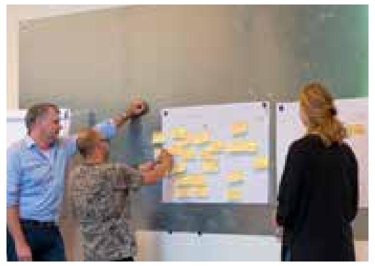


FUTURE FORMATS FOR APPLIED RESEARCH

Most current research and development projects deployed at university level are fully embedded within a historical grown academic culture. Well-known are core and fundamental research, free from any 'outside' influences and driven by inspired and ambitious researchers or research programs. Methods of conduct, analysis of results and the results themselves are solidly embedded in peer-reviews, financial systems, and academic award systems.

However, we see a growing need for innovation within the built environment industry. Traditionally a craftsmanship world seemingly embedded with many obstacles for this industry to radically develop. Hindered by relatively limited budgets (almost non-existent dedicated innovation budgets), by its nature of being project driven in combination with severe competition regulations and by a generally short-term financial outlook. Simultaneously this industry needs radical changes: energy transition, climate change, and raw material scarcity are just a few of the global challenges that need to be addressed. And especially these issues are currently investigated within various academic research contexts.

There is a need for a better, more efficient and effective collaboration between industry and academia. In terms of content, this is evident. Just as clear are the cultural gaps; different economies, time schedules, hierarchies, and management models, even though ambitions and tasks are aligned. There is a need for 'moderating'; to bridge academic knowledge and industry expertise, to facilitate



building industry in the transition from craftsmanship to high-tech, and to produce effective 'deliverables' by academic researchers.

Disciplines like 'IT' and 'energy' developed a dedicated culture for innovation, finance of research, and facilities for breeding start-ups and 'good ideas'. The built environment industry and the related university world seem mostly dependent on government-driven financial programs and formats for innovation and research. One can state that these 'other disciplines' can truly operate globally supported by multinational industries and interests. The built environment, while developing 'global knowledge', is per definition local and depending on regional industries and smaller economies. It seems clear that one can learn from other experiences and formats. Not to 'copy – paste' directly, but to borrow elements, to adapt and implement those that can improve an 'eco-system' for developing and applying built environment innovations. Obvious 'other' expertise ranges from crowd-funding to venture capitalist funding formats, including the associated 'business-side'. They unveil the need to improve a facilitating role for culture change in the industry to optimize and to expand the academic world of research characteristics: fundamental and applied.

Moderators
4TU.Bouw **Siebe Bakker**
creative projects **Dré Kampfraath**

Financial Experts
Startupbootcamp **Eric Broekhuizen**
Crowdlokaal **Marije Lutgendorff**

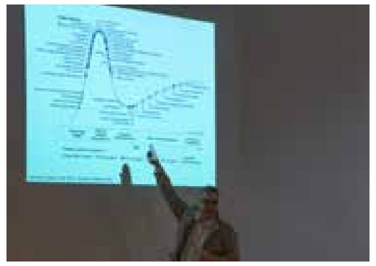
Participants
Delft University of Technology,
Henriette Bier, Frank van der Hoeven, Truus Hordijk, Tillmann Klein, Sina Mostafavi, Martin Tenpierik, Michela Turrin
Eindhoven University of Technology
Mariëlle Aarts, Alexander Rosemann, Stephanie Villegas Martinez
Fabrication Factory **Pieter Stoutjesdijk**
Recycled Island Stichting
Nienke Binnendijk
WHIM Architecture **Ramon Knoester,**
Zwarts & Jansma Architecten
Kay Oosterman

REAL ADDITIVE MANUFACTURING: REAL | DREAM

The potential for additive manufacturing (AM) in the built environment can be found in special products with small badge sizes. Using standardized systems is not always desired since almost every building is different. AM can be utilized for a lot of small parts embedded in our façades and especially for the complex parts where everything comes together. Integration of functions that could not be embedded yet is a large potential. Can adapting insulation be printed or can elements be printed on site, to deal with the different tolerances in the built environment

Along with the quest to find the real application of AM, certification is an issue. Each part is different, caused by a lot of parameters. Although for example, steel has the advantage of its strength, it is also unlikely that it will be used in critical parts, because the structural performance is hard to predict. Formwork or models used to make molds can be printed easily, which allows casting the final products itself. It is likely that till products can be certificated the non-critical parts will be printed directly and tested to obtain enough information about their behavior. Such non-critical parts can be found all over a façade.

The disadvantage of plastic printed products in the built environment is that they do not always have enough strength to be used as structural elements and are not that fire resistant. Next to those material characteristics, the anisotropic behavior, caused by the layered fabrication method, can be a



concern. This side effect has to be controlled better to minimize its presence. Or can it be utilized in a beneficial way?

AM Processes

To understand and use AM in a beneficial way the printing technologies have to be well understood. Probably not everything will be printed in future now the hype has come to its end. Now it is time to use it as a supplementary technology next to all other plastic processing technologies. Like very production technology the AM process is divided into certain steps;

1. Make a digital model, which defines the geometry
2. Export the model to an STL file.
3. Generate a G code from the STL file to control the machine.
4. Upload the file to the machine and start the production.
5. Unload the final product, which in some cases will need to go through a post processing process like sanding.

AM allows the production of nearly any geometrical form, but it is important to select the right production process. For every product the parameters will be different and because of that, the limitations of the different AM processes can easily become visible.

The most commonly used materials in Additive Manufacturing are polymers like ABS (Acrylonitrile butadiene styrene), PLA (Polylactic acid), PC (Polycarbonate), Polyamide (Nylon), Nylon 12, Glass-filled nylon, Epoxy resin, Wax and Photopolymer resins. Most of the materials are directly related to a certain production technology. For example, ABS can be extruded, not be polymerized.

Technologies

The AM technologies differ from each other based on the way the bonding process takes place. All common categories can be used for AM of plastics;

Binder Jetting

Binder jetting is a technique that selective depositions a layer of resin to selective bind a layer of powder material.

Directed Energy Deposition

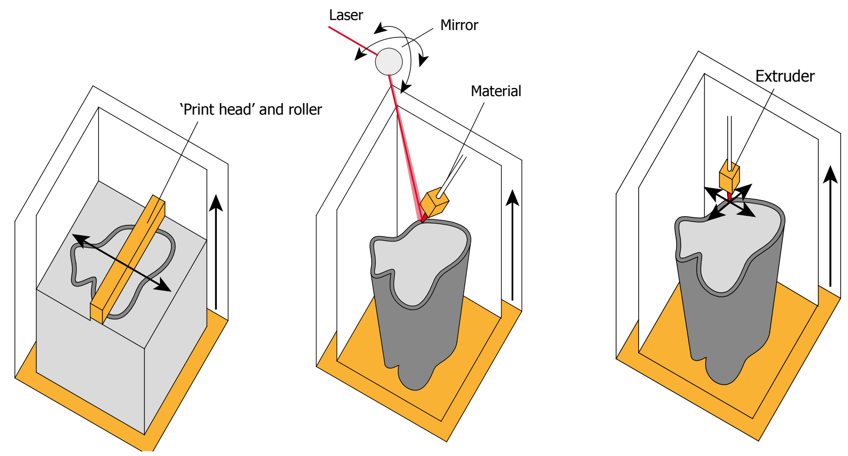
Directed energy deposition is considered as a complex printing process whereby the material is melted upon deposition with focused thermal energy, for example, a laser beam.

Material Extrusion

This technology is considered one of the most utilized techniques for additive manufacturing. The process is based on using heated extruders, which are fed with the filament material used to print the model. The extruders move in the x, y-direction while the building plate controls the z-direction movement. Some printers have fixed nozzles and a building plate that controls all the directions.

Material Jetting

Material jetting is a process that selectively drops droplets of material on top of each other. This could be wax or photopolymers that are hardened directly by use of a UV source.



Binder jetting

Directed energy deposition

Material extrusion

Powder Bed Fusion

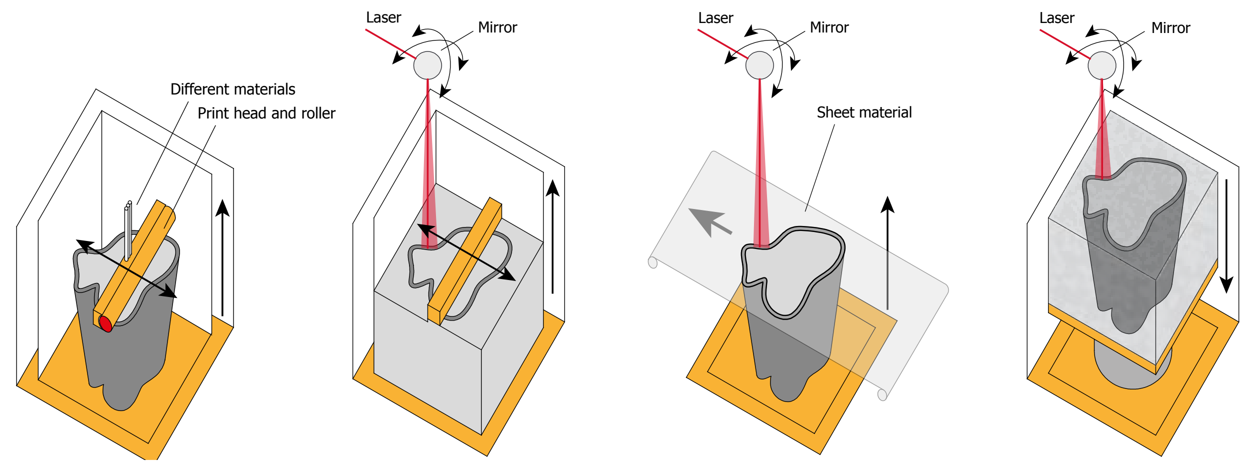
Powder bed fusion involves selective melting and re-solidification of powder beds. When plastic-based powder beds are used no additional support materials is needed, since the unbounded powder itself acts as a support material for the printed element.

Sheet Lamination

Sheet lamination is a process where prefabricated foils or sheets are used as print material. A knife or milling machine is used to cut the desired form, whereafter the sheets are attached on top of each other, using glue in case of paper and plastic, while ultrasonic welding is used in case of metals.

Vat Photo Polymerisation

Vat photo polymerisation involves the selective solidification of the liquid resin in a vat by use of a light source, for example, UV.



Material jetting

Powder bed fusion

Sheet lamination

Vat photo polymerisation

Moderator
4TU.Bouw **Siebe Bakker**

Presenters
Arup **Salome Galjaard**
Delft University of Technology
Henriëtte Bier, Ulrich Knaack, Dennis de Witte
G.tecz **Gregor Zimmermann**
TU Darmstadt **Oliver Tessmann, Alamir Mohsen**
University of Twente **Wessel Wits**

Text and Diagrams
Delft University of Technology
Dennis de Witte MSc.

	Metals	Ceramics	Polymers	Composites
binder jetting		3DP Inkjet	3DP	3DP
directed energy deposition	DLD DMD EBDM LENS LMD			
material extrusion		DIW FDM Robocasting	FDM FFF	FDM
material jetting			Material Jetting MJM Polyjet	
powder bed fusion	DMSL EBM SLM SLS	SLS	SHS SLS	
sheet lamination			LOM	LOM SDL
vat photo polymerisation			DLP SLA	

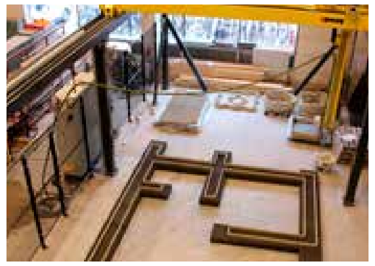
AM can be utilized for a lot of small parts embedded in our façades and especially for the complex parts where everything comes together.

REAL ADDITIVE MANUFACTURING: 3D CONCRETE PRINTING

In steeds meer disciplines vindt 3D printen toepassingen. De meest uiteenlopende producten kunnen met deze techniek worden gemaakt; een steeds breder scala aan printbare materialen is daarvoor voor handen. Hoogwaardige, geometrisch complexe producten zoals machineonderdelen uit gesinterd metaalpoeder winnen terrein. Maar ook lekkernijen van geprinte chocolade en suikerwerk lijken een toekomst te hebben. De mogelijkheid tot mass-customization (het massaal vervaardigen van unieke voorwerpen) vindt haar ultieme toepassing in het 3D printen van medische protheses.

In de bouwwereld wordt de techniek nu zo'n 15 jaar toegepast voor het maken van maquettes, het beoordelen van verbindingen en details, e.d. Sinds een paar jaar wordt voorzichtig de stap gemaakt naar het printen van gebouwen en bouwdelen. Er wordt geëxperimenteerd met het printen van diverse materialen, waaronder staal, kunststof, hout, glas en beton.

Het 3D printen van betonachtige materialen gebeurt op ongeveer een dozijn plaatsen in de wereld. Een aantal bedrijven en een paar universiteiten, onder andere in Italië, Engeland, de VS, China en Nederland, experimenteren ermee. In China zijn al huizen en een meerlaags kantoorgebouw met behulp van deze techniek gerealiseerd.



Eindhoven University of Technology
prof.dr.ir. **Theo Salet**,
prof.ir. **Juliette Bekkering**,
prof.Dr.-Ing **Patrick Teuffel**,
Rob Wolfs MSc.,
Zeeshan Ahmed MSc.,
dr.ir. **Freek Bos**, ing. **Cor de Bruijn**

Ballast Nedam

Bekaert

Concrete Valley

CRH

CyBe

SGS Intron

Stichting SKKB

Van Wijnen

Verhoeven Timmerfabriek

Weber Beamix

Witteveen+Bos

Alhoewel niet bekend is wat in die projecten precies wél en wat niet daadwerkelijk geprint is, zijn dit onmiskenbaar belangrijke eerste stappen naar een toekomst waarin het 3D printen een belangrijke techniek zal zijn voor de realisatie van gebouwen.

Het 3DCP project van de TU Eindhoven wordt ondersteund door een groep bedrijven die deze toekomst voor zich ziet. Samen vormen ze een groep waarin de hele maak-keten vertegenwoordigt is: cementleveranciers, betonbedrijf, aannemer, ingenieursbureau. Eén van de bedrijven verkent zelf ook de mogelijkheden van het beton printen.

De 3D beton printer van de TU/e staat in het Pieter van Musschenbroek-laboratorium van de faculteit Bouwkunde. De printer bestaat uit een portaalrobot met vier vrijheidsgraden (x, y, z en rz) en een intern 'printbed' van 9,0 × 4,5 × 2,8 m, aangestuurd door servo-motoren. De machine is voorzien van een Siemens Sinumerik 840 sl motion controller, die werkt op basis van zogenaamde G-Code. Dergelijke controllers worden vaak gebruikt in de CNC-gestuurd boren en frezen. De portaalrobot is via een flexibele slang verbonden met een MTec DuoMix 2000 beton pomp/mixer. De pomp is ook verbonden met de controller waardoor de bewegingen van de robot (snelheid, versnelling, rotatie) gekoppeld kunnen worden aan de toevoer van beton.

Dat het 3D beton printen veel potentie heeft is duidelijk. Maar de vraag hoe deze het beste benut kan worden, is veel minder makkelijk te beantwoorden. Om een stip aan de horizon te kunnen zetten, heeft Tektoniek in samenwerking met Booosting een Design Challenge opgezet. Uitdaging: 'doe een ontwerpvoorstel voor een bouwwerk dat optimaal gebruik maakt van de potenties die 3D-betonprinten lijkt te bieden'. De uiteenlopende resultaten die dit opleverde onderstreept wel hoe breed de mogelijkheden zouden kunnen zijn. Drie projecten werden geselecteerd. Het onderzoeksteam is met de projectteams aan de slag gegaan om te kijken welke eerste stappen gezet konden worden om de concepten te realiseren. Daarbij is geëxperimenteerd met de vorm van de spuitkop, het printen op gekromde ondergrond, uitkragingen, het printen van splines, etc. De techniek is in dat proces een stuk beter onder controle gekregen, de do's and dont's zijn boven water gekomen.

Tegelijkertijd zijn ook de uitdagingen voor de komende jaren naar voren gekomen. In de eerste plaats moet de vormvrijheid – de belofte van 3D printen – gerealiseerd gaan worden. Hiervoor moeten uitkragingen geprint kunnen worden. Dat vraagt ook om een ondersteuningsmateriaal. Verder moet het printmateriaal gekarakteriseerd en geoptimaliseerd worden. Gedacht moet worden aan de relaties tussen viscositeit, groene sterkte en stijfheid, uitgeharde sterkte, uithardingssnelheid, hechting van laag op laag, etc. Voor constructieve toepassingen is de vraag hoe veilig (plastisch) bezwijkgedrag moet worden verkregen, voor de hand liggend.

Verschillende voorstellen uit de Tektoniek/Booosting Design Challenge voorzien ook in het gebruik van meerdere (beton)materialen door elkaar, bijvoorbeeld een isolerend beton op de ene plek en een constructief beton op de andere. Omdat de printkop tijdens het productieproces overal in de constructie minimaal één keer komt, behoort een dergelijke optimalisatie tot de mogelijkheden. Dit is bij uitstek de 'kleurenprinter' die de onderzoeksgroep voor zich ziet: een betonprinter die een element precies zo op kan bouwen dat het op elke plek de eigenschappen bezit die het nodig heeft, ook al kunnen die voor elk opvolgend element totaal anders zijn. En daar wordt aan gewerkt!

CITY OF THINGS – CONFERENCE

During the closing event of SOUL-FI, CLICKNL organized a conference aimed at developing a better understanding of the implications and potentials of the Internet of Things for 'built environment' professionals and students, especially designers. IoT is definitely going to play a major role in our societies and designers, policymakers and entrepreneurs should be well aware of its possibilities. Any development related to IoT will find its place within our cities and homes.

Alongside workshops on technology and city making, a hackathon for students and professional researchers was organized in collaboration with Eneco and the Science Centre Delft. Based on Eneco's 'Toon' (smart) thermostat, that continuously measures a wide variety of data points, participants were challenged to look beyond the obvious temperature regulation of homes. What could a tool like 'Toon' offer more, either as a hub on the scale of a house or as part of city-wide data-driven systems?

SOUL-FI start-ups pitched at the end of the conference to an audience of potential clients (municipalities) as well as investors.

in collaboration with
ClickNL and SOUL-FI

4TU.Bouw **Siebe Bakker**
bureaubakker **Elise Buiter**
creative projects **Dré Kampfraath**
Delft University of Technology
Frank van der Hoeven
SOUL-FI Nuno Varandas

Participants Conference
Bernardo Alves, Michael Anhalt, David Barroso, Hannah Beljaars-Frederiks, Witali Bytschkow, Carlos Carreiras, Jonathan Carter, Corrado Cervellati, Angela Corbari, Angela Corbari, Véro Crickx, David Custódio, Sandra de Vries, Xander den Duijn, Martin Dennemark, Martin Dobler, Zadi Douhoure, Steve Simon, Stefano Maria Esposito, Michiel Fremouw, Gianfranco Gabriele, Giacomo Gallo, Victor Gevers, Vasco Gouveia, Vitor Graveto, Dimitrios Kyritsis, Andre Lourenco, Susana Lourenço, Maria Augusta Mancini, Barbara Massacci, Ingrid Mulder, Eduardo Natividade, Cyntha Nijmeijer, Anna-Maria Ntarladima, Fco. Javier Núñez García, Walter Nunziati, Maria Dolores Ordoñez Martinez, Juan Ortells, David Eugenio Pajares de Santiago, Víctor Pérez Tapia, David Pond, Robin Puthli, Joana Rafael, Alvaro Rojo Perez, Daniel Russo, Nadwah Samat, Marco Scerbo, Stan Scheerder, Iskander Smit, Bart Staats, Micaela Surchi, Evangelos Theocharous, Manuela Triggianese, Herman van Wamelen, Hugo Vandenborre, Roeland Vanrenterghem, Bart Staats, Sabine de Milliano, Nuno Sousa, Matías Daporta, Gian Andrea Giacobone, Marco Knol, Peter van Waart, Jan Willem Smeenk, Piet Jan van Wier, Gerrit Jan van 't Veen, Jan Kadijk, Arjen Hof, Anne Nighten, Jennifer Schubert

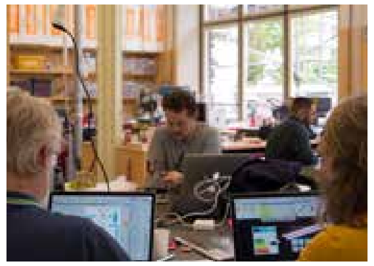
Participating 'Clients & Investors'
DC Ventures **Diamantino Costa,** Eneco **Glenn Bijvoets, Hans-Jaap Moes,** Henq **Eric van Keimpema,** Keadyn **Tom van 't Noordeinde,** Municipality of Coimbra **Nuno Pomar,** Municipality of Dordrecht **Cunera Smit & Ton Mol,** Municipality of Fundao **Ricardo Goncalves,** Municipality of Rotterdam **Frank Vieveen,** Municipality of Waalre **Nan Zevenhek,** Municipality of Utrech **Thomas Kruse & Brigitte Hulscher,** My Micro Invest **Roland Nobels,** Cottonwood **Ray Quintana**

CITY OF THINGS – HACKATHON

During the closing event of SOUL-FI, CLICKNL organized a conference aimed at developing a better understanding of the implications and potentials of the Internet of Things for 'built environment' professionals and students, especially designers. IoT is definitely going to play a major role in our societies and designers, policymakers and entrepreneurs should be well aware of its possibilities. Any development related to IoT will find its place within our cities and homes.

Alongside workshops on technology and city making, a hackathon for students and professional researchers was organized in collaboration with Eneco and the Science Centre Delft. Based on Eneco's 'Toon' (smart) thermostat, that continuously measures a wide variety of data points, participants were challenged to look beyond the obvious temperature regulation of homes. What could a tool like 'Toon' offer more, either as a hub on the scale of a house or as part of city-wide data-driven systems?

SOUL-FI start-ups pitched at the end of the conference to an audience of potential clients (municipalities) as well as investors.



in collaboration with
ClickNL, Science Center Delft and SOUL-FI

4TU.Bouw **Siebe Bakker,**
bureaubakker **Elise Buiter,**
Kim Degen, Mariet Sauerwein
creative projects **Dré Kampfraath,**
Frans Schupp
Eneco **Dennis Ramondt, Ronald Root**
Delft University of Technology
Matthijs de Deckere,
Frank van der Hoeven
Science Center Delft **Teun Verkerk**

Participants Hackaton
Regina Bokel, Jacky Bourgeois, Sommer Cade, Balasz Dukai, Simon Griffioen, Duygu Kaynak, Eric Lowe, Sadie Meyer, Pirouz Nourian, Stefan van der Spek, Tom Commandeur, Ravi Peters, Martin Dennemark

REAL ADDITIVE MANUFACTURING: PROTOTYPING | PRODUCTION

The second REAL ADDITIVE MANUFACTURING conference dealt with the topic of 'Perfect for Prototyping or Promising for Production'. Based on a series of presentations of implemented and researched additive manufacturing techniques, the speakers debated with the audience on the current state of these technologies. Together they explored the potential for future implementations as well as various challenges to take on. Varying from regulations and safety to the desire for building unique freeform elements or perfectly fitting renovations, a score of relevant topics was discussed among researchers, students, and industry professionals.








Moderator
Siebe Bakker

Support
Elise Buiter

Lecturers
Marcel Bilow,
Lenneart van Capelleveen,
Jeroen Coenders,
Chris Borg Constanzi, Ulrich Knaack,
Paul de Ruiter, Valentini Sarakinioti,
Roel Schipper, Holger Strauss,
Michela Turrin, Dennis de Witte,
Aant van der Zee


RESEARCH TO REALITY – BOOTCAMP

Prior to the Research to Reality Conference around 35 researchers selected to pitch for Lighthouse Project 2017 funding or 'start-up' collaborations joined a two-day 'bootcamp' to prepare.

Research and product ideas were presented and critiqued. Leading to more focused and structured storytelling. Professionals from the financial- and start-up world presented valuable insights for taking a leap towards the industry.

The bootcamp ended with a workshop on the art of pitching by a TED-talk pitch trainer.

Moderators
4TU.Bouw **Siebe Bakker**
creative projects **Dré Kampfraath**

Experts
Socrates **Hans-Jaap Moes**
David Beckett
Carlien Roodink Consultancy
Carlien Roodink

Support
bureaubakker **Elise Buiter**

Participants
Hosseiny Alamday, Ana Anton, Juan Azcárate-Aguerre, Bram Botterman, Telesilla Bristogianni, Miktha Farid, Arjan Habraken, John Hanna, Carola Hein, Christian Louter, Marie de Klijn, Thaleia Konstantinou, Roel Loonen, Mladena Lukovic, Sina Mostafavi, Koen Mulder, Pirouz Nourian, Faidra Oikonomopoulou, Léon olde Scholtenhuis, Ioulia Ossokina, Arno Pronk, Patrycja Pustelnik, Seyed Sedighi, Foteini Setaki, Anne Struiksma, Martin Tenpierik, Michela Turrin, Farid Vahdatikhaki, Tommaso Venturini, Edward Verbree, Qinyu Wang, Guang Ye, Cas van der Zanden












RESEARCH TO REALITY – CONFERENCE

On November 30 the first Research to Reality Conference was held at the New Institute in Rotterdam. Researchers from the four universities debated on future ambitions and urgencies. Based on their expertise in previous research projects four themes were discussed; Smart Cities, Energy Transition, Circular, and Resilience. These four themes are generally acknowledged to become serious topics for the next decade. It only seems prudent to start debating the positions and potentials of the universities on how to respond, prepare and lead.

During the second part of the conference, sixteen teams pitched to an academic and industry audience for Lighthouse Projects 2017 funding. Eight teams were awarded and will develop a 'proof of concept' or 'proof of failure' before the end of 2017.

Seven researchers pitched for funding or collaboration on products and ideas that have already reached the 'proof of concept' stage. They want to take their results to an entrepreneurial level. Two companies presented their research questions calling for researchers to team up and take on their challenges.

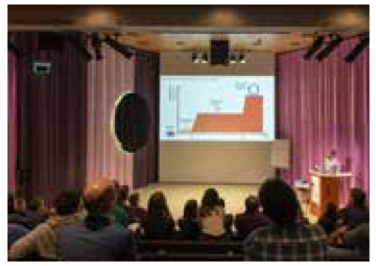
Research to Reality is an initiative to combine the worlds of academics and industry. To initiate and facilitate meaningful collaborations. To set the stage for joint ambitions and goals. And to host a focused, topic-driven and lively exchange of ideas and passions.

Moderators
4TU.Bouw **Siebe Bakker**
creative projects **Dré Kampfraath**

Lecturers
University of Twente **André Dorée**
UNStudio **Rob Henderson**
Delft University of Technology
Frank van der Hoeven, Ulrich Knaack
4TU.Bouw **Alexander Schmets**
Summum / Block Research Group, ETH Zürich **Diederik Veenendaal**
Eindhoven University of Technology
Bauke de Vries

Support
bureaubakker **Elise Buiter**, **Kyra Galjee**

Participants
**Aant van der Zee, Alex Wandl,
Ana Anton, Anna Maria Ntarladima,
Anne Struiksma, Anupam Kumar,
Arjan Habraken, Arno Pronk,
Bahman Ghiassi, Bahman Hashemi,
Bram Botterman, Carlien Roodink,
Carola Hein, Cas van der Zanden,
Chen Hung Chu,
Chris Borg Constanzi,
Christian Louter, Cindy Vissering,
Davide Leonetti, Denis Makarov,
Dennis Ramondt, Dick Vlasblom,
Edward Verbree, Ella Braat,
Enayat Hosseini Aria, Erwin Jacobs,
Faidra Oikonomopoulou,
Farid Vahdatikhaki, Feixiong Liao,
Foteini Setaki, Freek Bos,
Gamze Dane, Hans-Jaap Moes,
Haydee Sheombar, Henriette Bier,
Hosseiny Alamday, Ioulia Ossokina,
Jan de Boer, Janine Profijt,
Javid Jooshesh, Jia Guo, John Hanna,
Joyraj Chakraborty, Juan Azcarate,
Koen Mulder, Léon olde Scholtenhuis,
Lida Barou, Maarten Hommelberg,
Marcel Bilow, Maria Hänsch,
Marie de Klijn, Mark van Erk,
Martin Tenpierik, Michela Turrin,
Michiel Ritzen, Miktha Farid,
Mladena Lukovic,
Nadia Remmerswaal, Panos Sakkas,
Patrycja Pustelnik, Paul de Ruiter,
Pauline van den Berg,
Perica Savanovic,
Piet van Staalduinen, Pirouz Nourian,
Priya Darshini Cheyyar Nageswaran,
Qingpeng Li, Qinyu Wang,
Richard Giesen, Rijk Blok,
Roel Loonen, Roel Schipper,
Ronald Root, Samaneh Rezvani,
Seyed Sedighi, Sina Mostafavi,
Stephen Galsworthy,
Telesilla Bristogianni,
Thaleia Konstantinou,
Tommaso Venturini, Torsten Schröder,
Truus Hordijk, Vagos Theocharous,
Valentini Sarakinioti, Wen Jiang,
Wenshu Li, Wiwi Tjiook,
Wouter Beelen, Xiaoteng Pan**



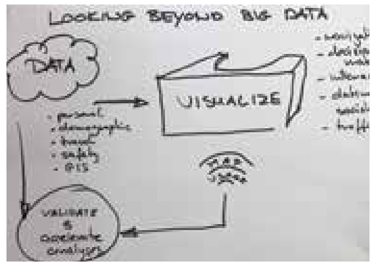
CITY OF REALITIES

On the longest day of the year 4TU.Bouw teamed up with ClickNL and KNOB to host a workshop and seminar on virtual and augmented reality in relation to life in our cities.

In the workshop around 30 participants from various backgrounds - architecture, heritage, museums, social sciences, information technology - where challenged to investigate the potentials of these new technologies. Besides benefits and opportunities, all kind of hurdles, privacy issues and 'loss-of-imagination' became part of inventories. Ideas ranged from simultaneously experiencing past, present, and future, to personalised commercials and wayfinding, and a range of services interconnecting with upcoming 'Internet of Things' availability.

The evening program presented lectures by professionals with experience in research and development of AR/VR technologies. It provided a wide-ranging insight into the current state of initiatives around this theme.

The main goal of the day was to get the various professionals and students together. To exchange ideas and experiences, to provide opportunities to start collaborating and bundling the different technologies and expertise needed to further develop implementations of virtual reality and augmented reality into our cities.



in collaboration with
ClickNL and KNOB

Organisers
4TU.Bouw **Siebe Bakker**
ClickNL & Delft University of Technology
Frank van der Hoeven
KNOB & Delft University of Technology
Judith Fraune

support (@Hok)
Delft University of Technology
Arno Freeke, Arend-Jan Krooneman

Lecturers
Delft University of Technology
Arno Freeke, Arend-Jan Krooneman, Carola Hein
Meertens Instituut / NWA route Levend Verleden **Patricia Alkhoven**
NOV'82 Architecten **Laura Ubachs**
UNStudio **Bart Chompff, Bao An Nguyen Phuoc**

Workshop Moderators
Siebe Bakker, Elise Buiter, Patricia Hessing, Jasper Westebring, Dré Kampfraath

Workshop VR/AR experts (@Hok)
Liviu Paicu, Firat Isik, Max van Schendel, Thomas Meut, Arend-Jan Krooneman

Workshop Participants
Harry Vleems, Charlotte van Emstede, Emily Taylor, Liang Xiong, Loes Thijssen, Bereddin Ghazal, Rik Tersteeg, Norman Langelaan, Micah Johnson, Marthe Stallenberg, Bart Molendijk, Wim Kievits, Danhua Xu, Dejian Peng, Hayo Wagenaar, Marjanne Statema, Maurice de Kleijn, Vanessa Vidal Ladera, Maarten Reiling, Wibke Plagmann, Richard van Os, T.C.Dai, Thijs Bennebroek, Damien Vurpillot, Trevor Tanzi, Kaiyi Zhu, Dennis Dekker, Gaudi Hoedaya, Jephta Dullaart, Stefan van der Spek, Karen Schenk, Susan Ng-A-Tham, Lida Aminian, Olav Reijers, Anna Stolyarova









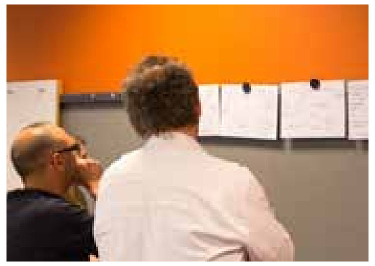



INFOGRAPHICS

Infographics Workshops
Infographics 2014 – 2017

One of the goals the 4TU.Bouw team had set for itself was to facilitate the development of specific 'professional skills' for their researchers, in addition to those offered in the respective curricula. For all researchers of granted Lighthouse Projects, a workshop was organised at the start to translate their research proposals and aims into clear and inviting infographics. An exercise that proved to offer structured insights into their processes as well as into ways of communicating with non-academics.

This 'Infographic' format was extended to PDEng and Ph.D. researchers from various faculties for exactly the same objectives.



INFOGRAPHIC WORKSHOPS

for Lighthouse Project teams, PDEng & Ph.D. researchers

In order to support researchers in developing graphic representations of their projects 4TU.Bouw offers workshop sessions on infographics, organized by bureaubakker and creative projects. They result in professionally produced content. They also improve individual skills on presentation and storytelling and often help with sifting core elements from details.

Each workshop starts with short presentations by the researchers on their projects. Immediate feedback helps to identify the main ambitions, relevance, processes and envisioned results.

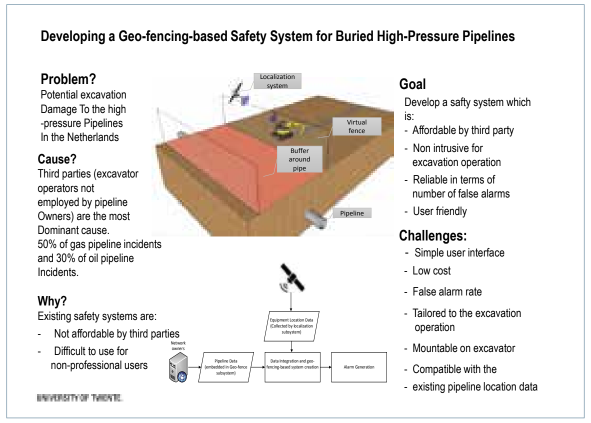
A general introduction on infographics based on content, design, sharability and storytelling kicks off a working session for the participants in which they have to produce a first sketch of their proposals in a limited amount of logic steps. They are challenged to use as little text as possible and assisted during this phase with feedback on all four levels.

In the last part of the workshop, the sketches are presented to 'a new pair of eyes' interpreting the work without verbal explanations from the participants. Loopholes and gaps in the story, unclear symbols, and missed opportunities are thus unveiled.

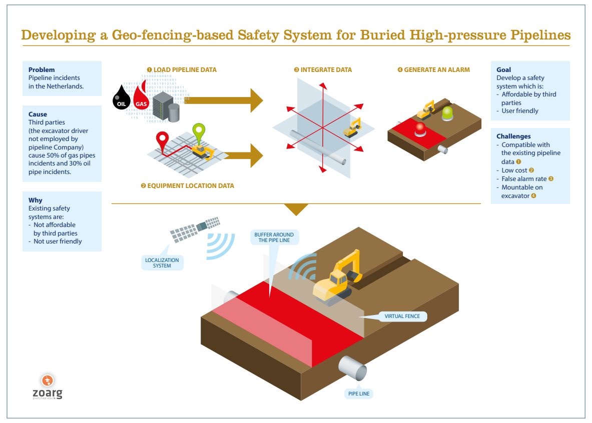
The following weeks the sketches are further developed by professional designers - in dialogue with the researchers - into clear infographics.

Moderators
Siebe Bakker, Dré Kampfraath

Graphic Design
2014 **Ad van der Kouwe**
2015 – 2017 **Dré Kampfraath, Frans Schupp**

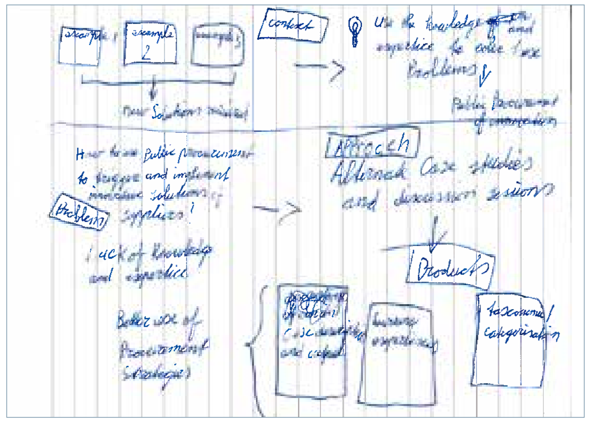


Updated result workshop session

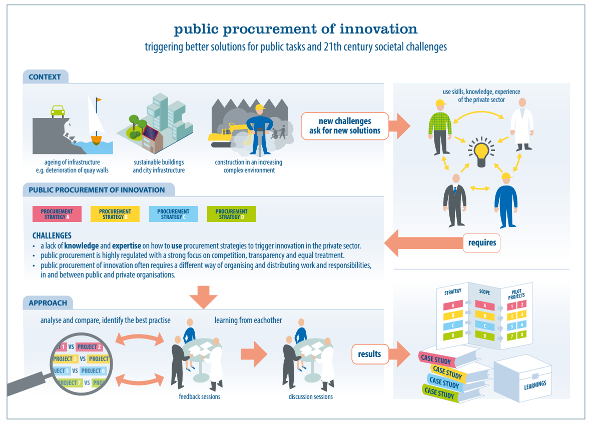


Final vesion

Saeid Asadollahi, Eindhoven University of Technology

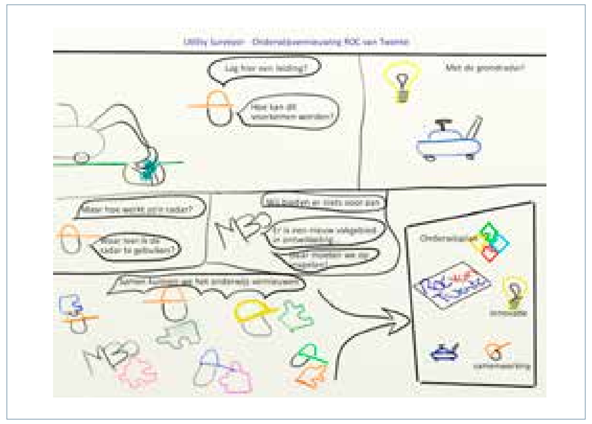


End result workshop session

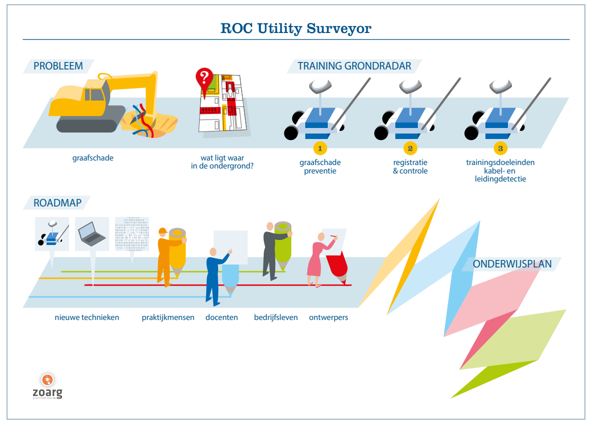


Final vesion

Bart Lenderink, University of Twente

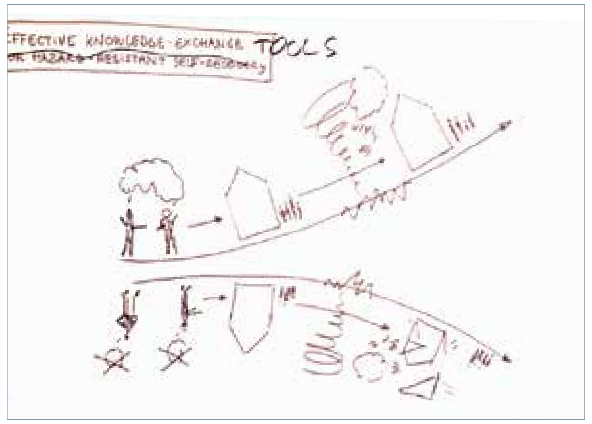


Updated result workshop session

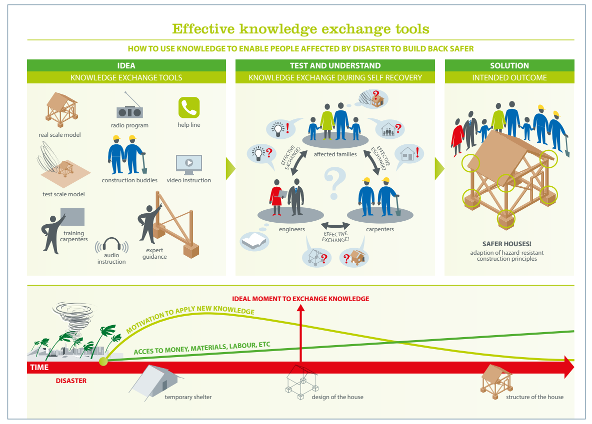


Final vesion

Diewertje ten Berg, University of Twente

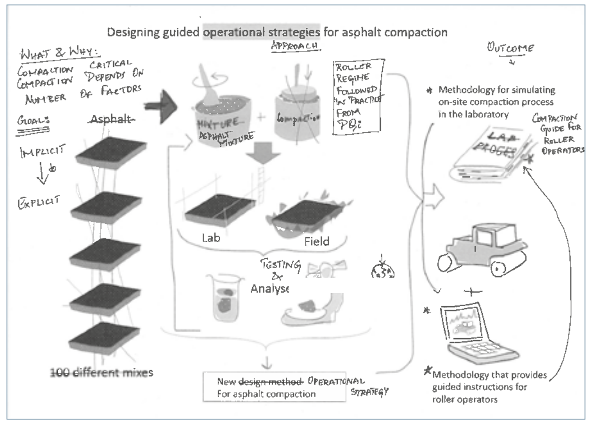


End result workshop session

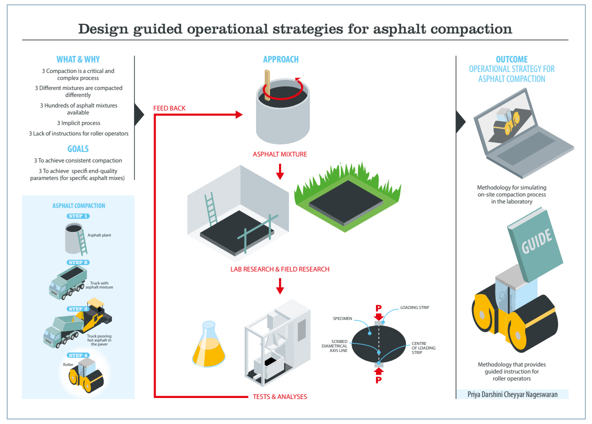


Final vesion

Eefje Hendriks, Eindhoven University of Technology

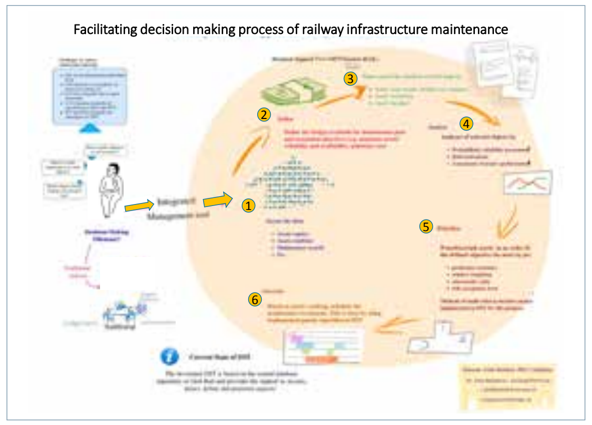


First sketch creative projects

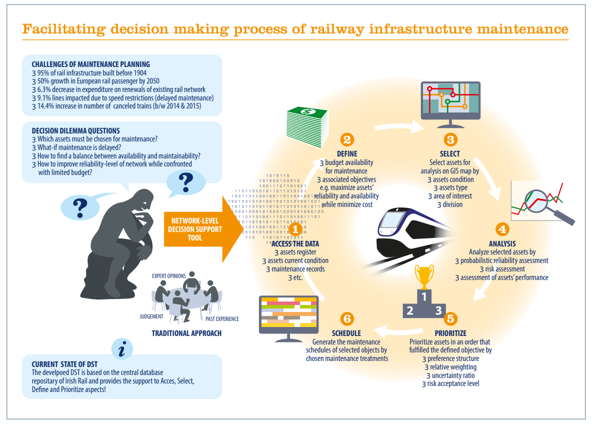


Final vesion

Priya Darshini Cheyyar Nageswaran, University of Twente

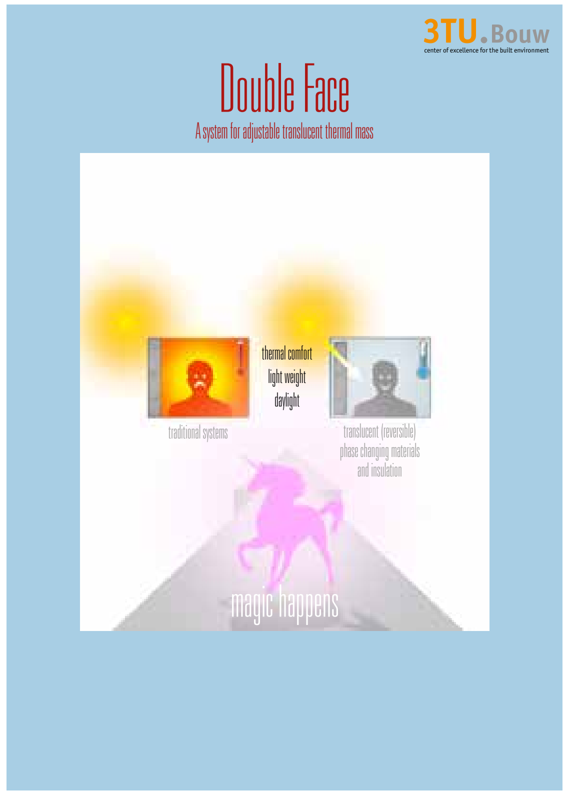


Third sketch creative projects



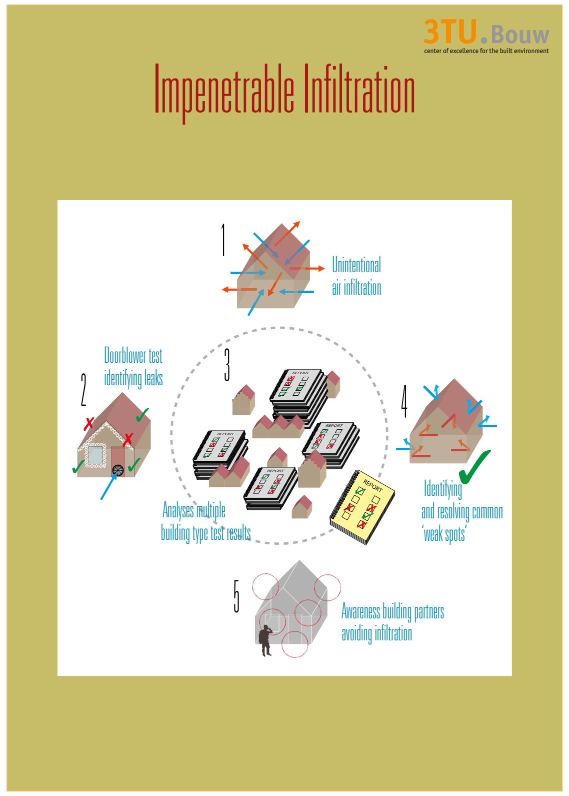
Final vesion

Zahara Allah Bukhsh, University of Twente

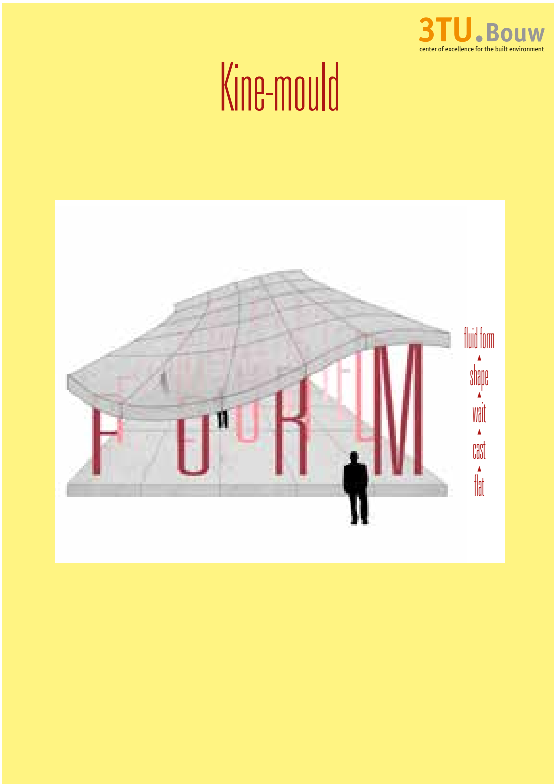


dr.Arch. **Michela Turrin**,
Delft University of Technology, Lighthouse Project 2014

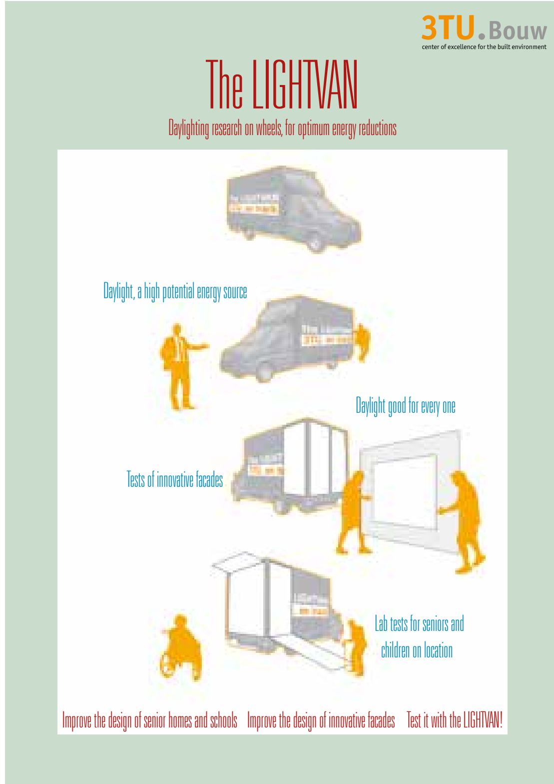
prof.Dr.-Ing.habil. **Alexander Rosemann**,
Delft University of Technology, Lighthouse Project 2014



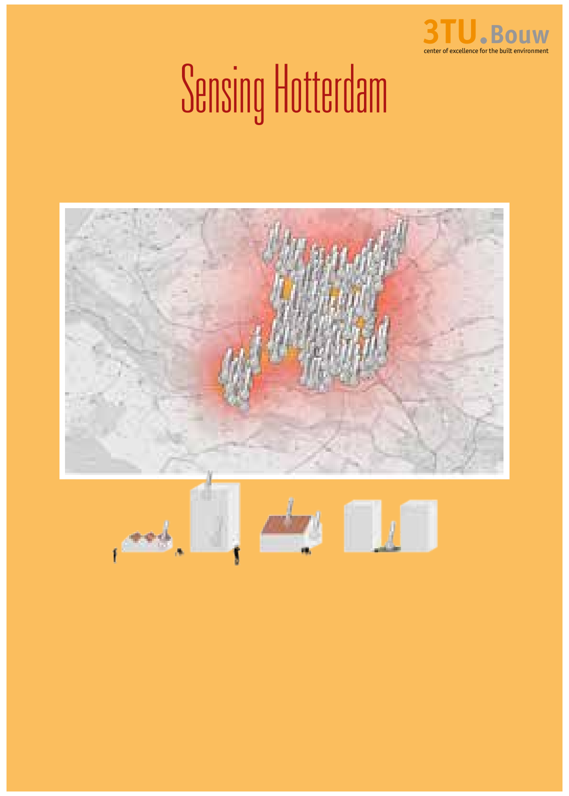
dr.ir. **Bram Entrop**,
University of Twente, Lighthouse Project 2014



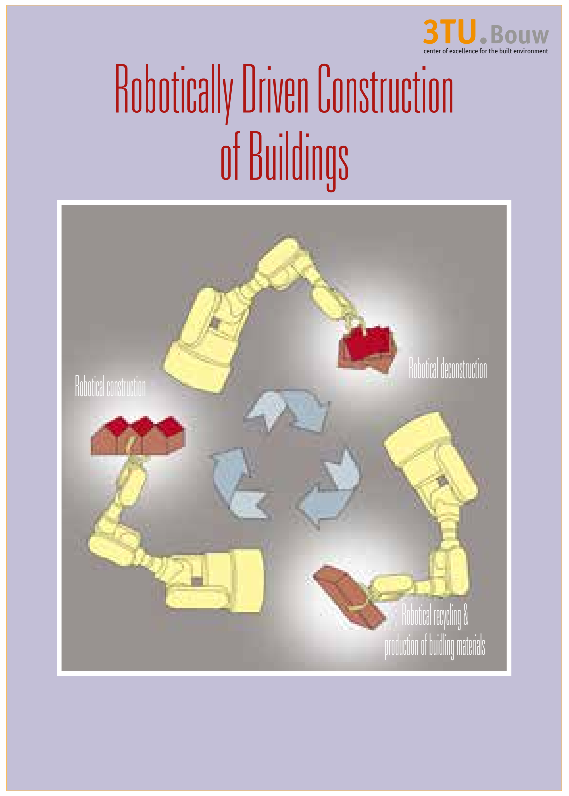
ir. **Roel Schipper**,
Delft University of Technology, Lighthouse Project 2014



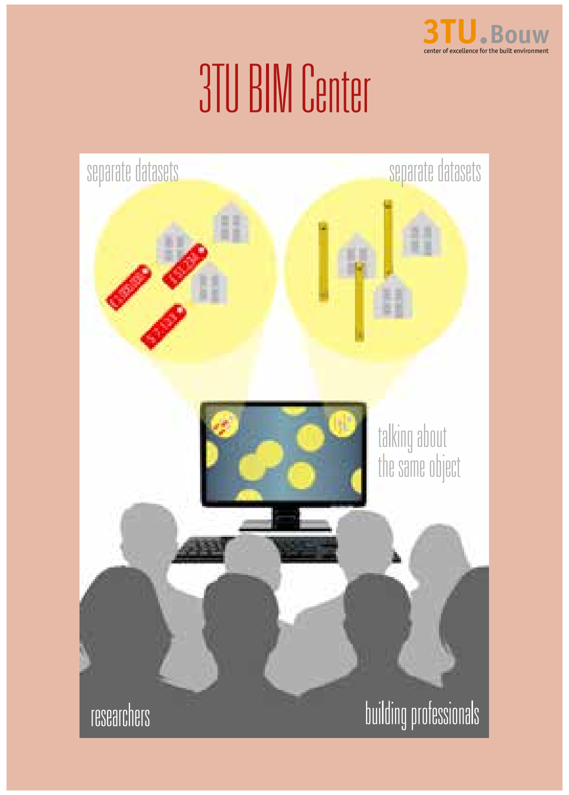
assoc.prof.dr. **Truus Hordijk**,
Delft University of Technology, Lighthouse Project 2014



dr.ir. **Frank van der Hoeven**,
Delft University of Technology, Lighthouse Project 2014

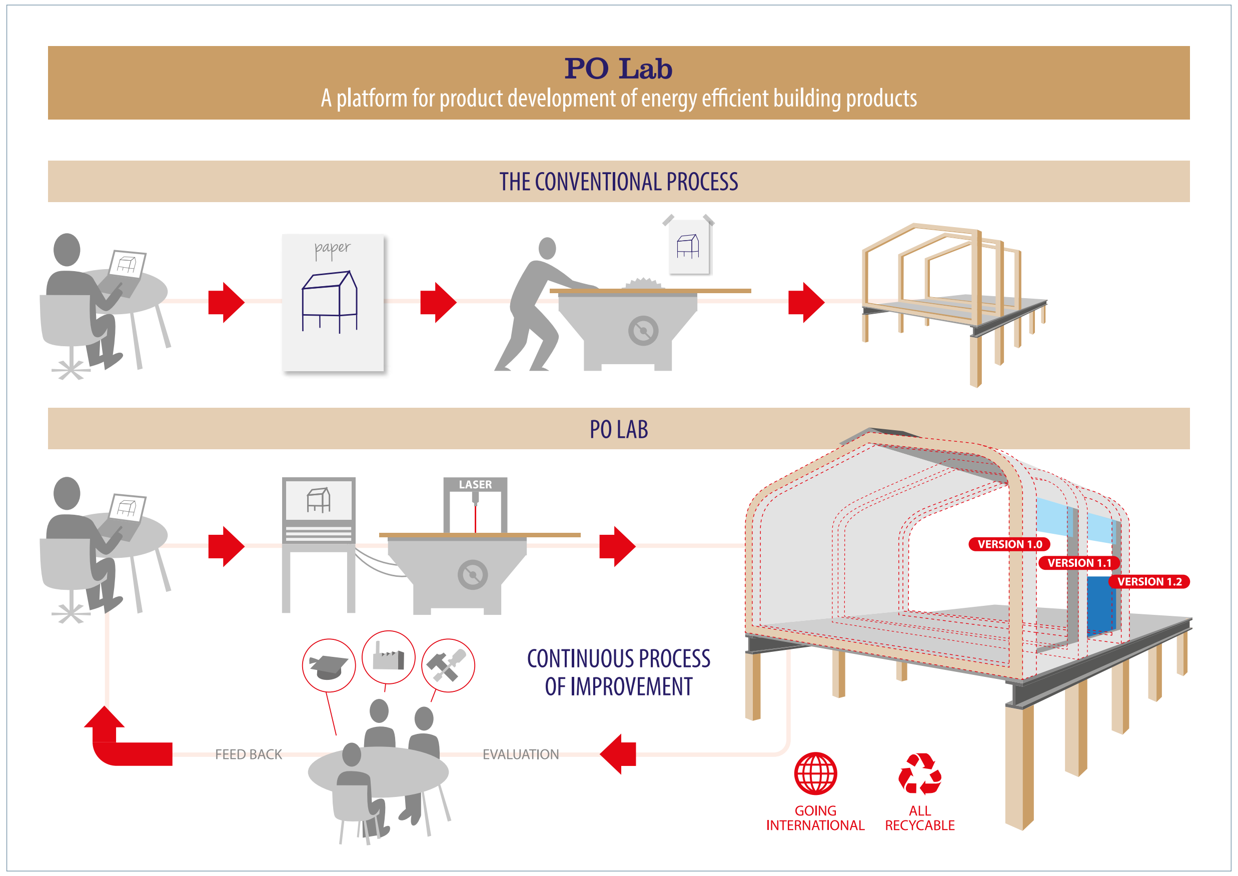


Dr.-Ing. **Henriette Bier**,
Delft University of Technology, Lighthouse Project 2014

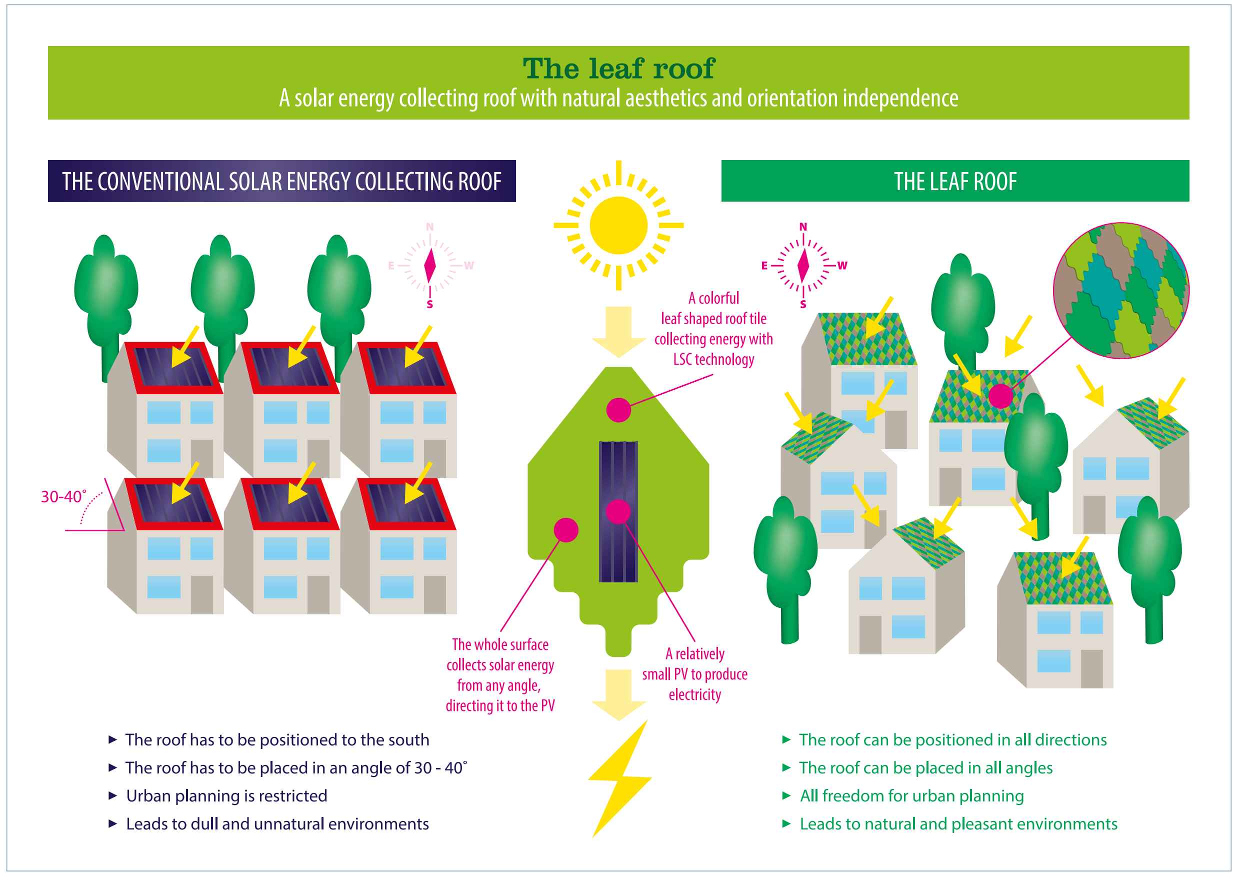


dr. **Timo Hartmann**,
University of Twente, Lighthouse Project 2014

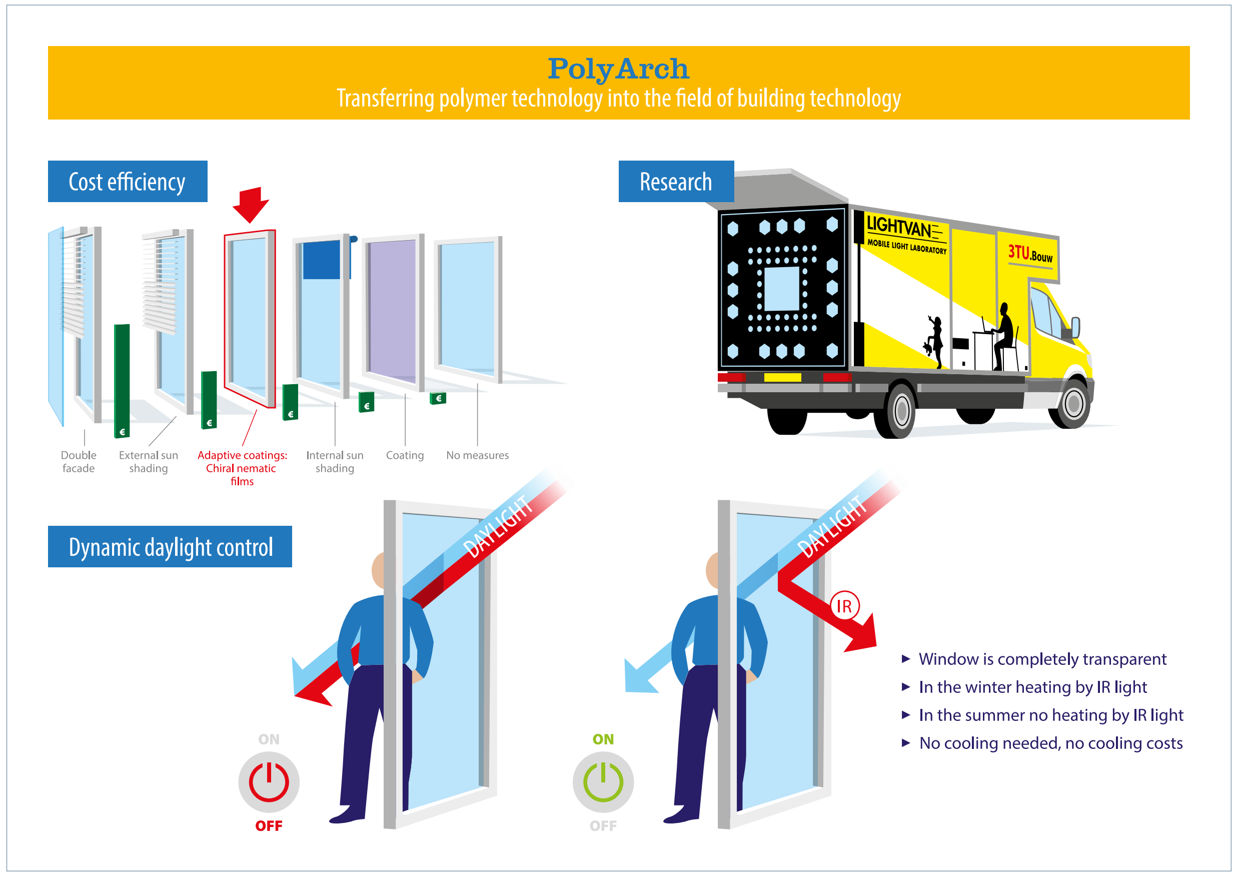
Prof.dr..ing. **Carola Hein**, Delft University of Technology, Lighthouse Project 2015



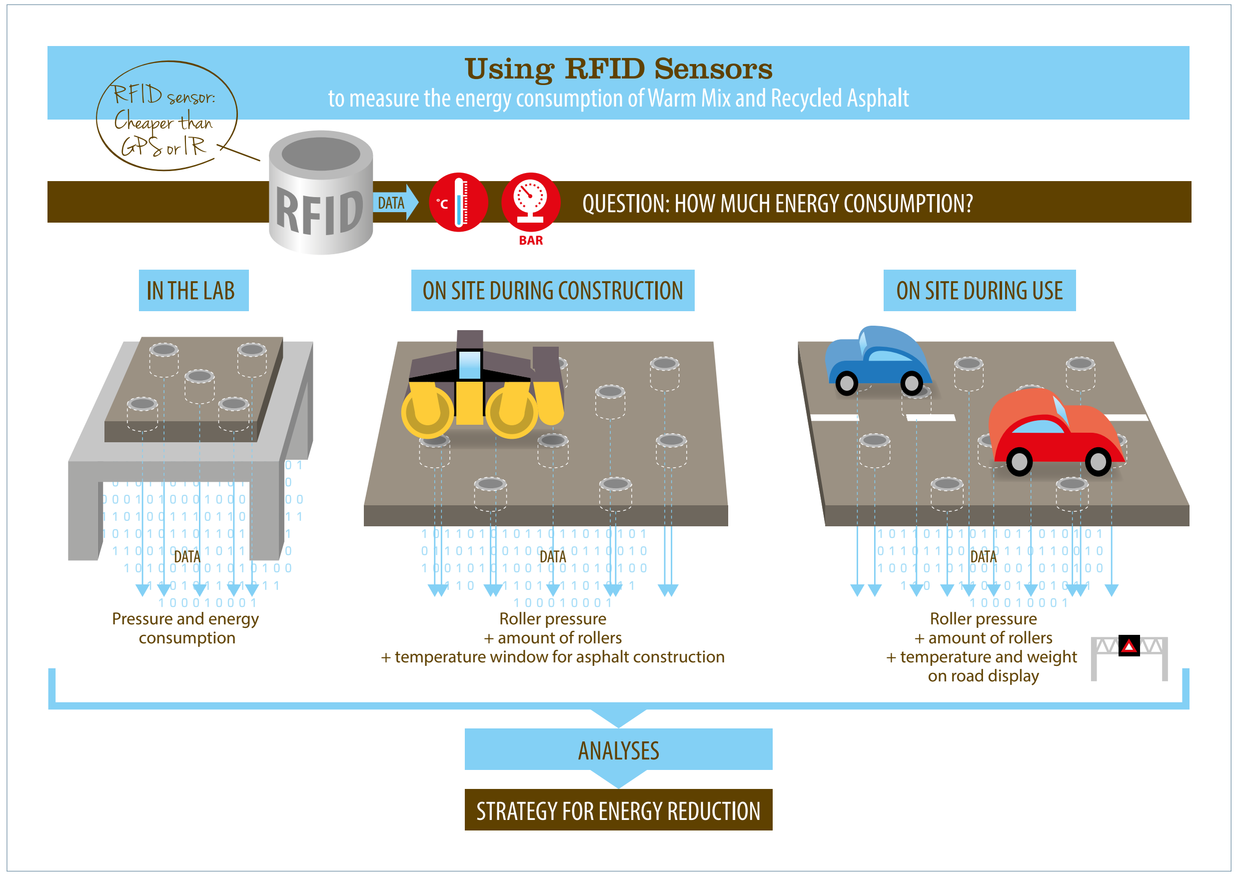
Dr.-Ing. **Marcel Bilow**, Delft University of Technology, Lighthouse Project 2015



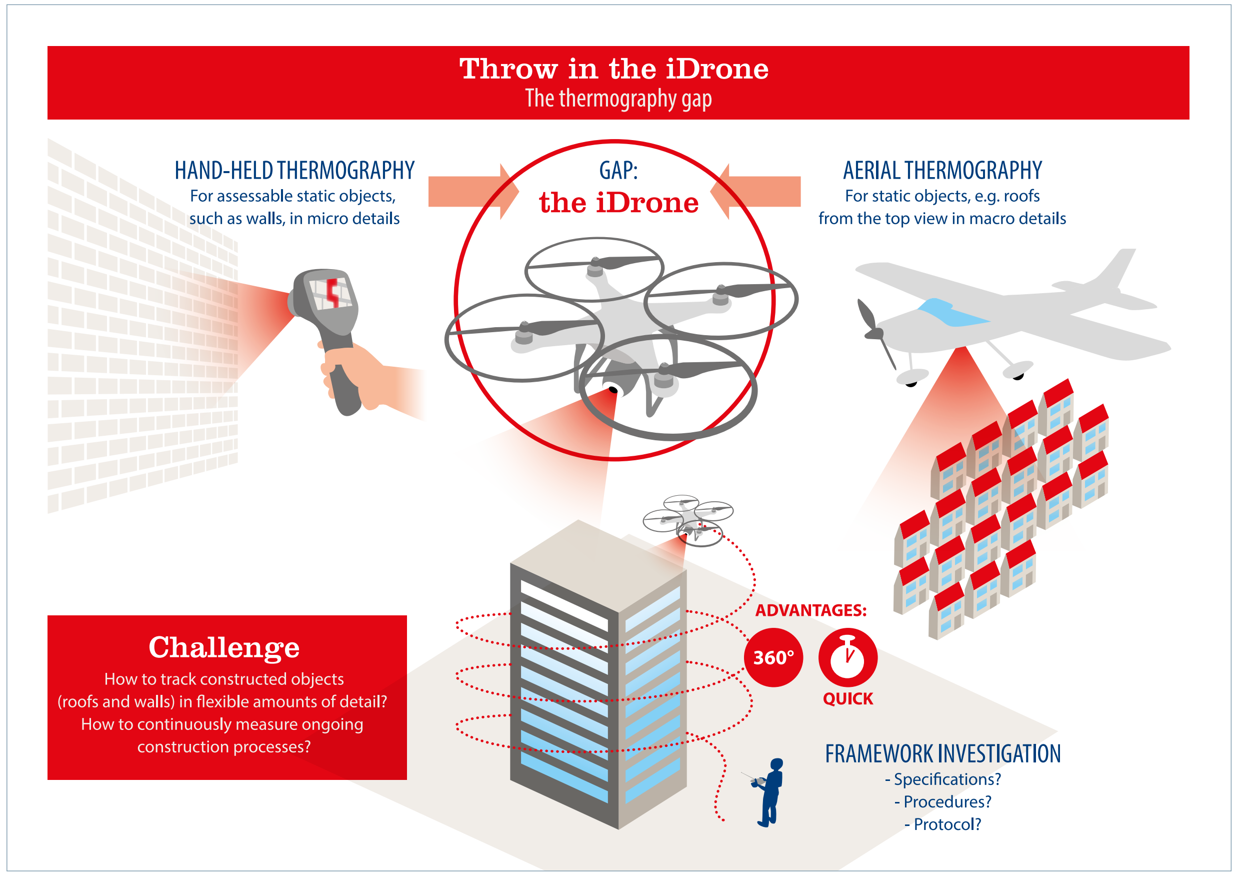
prof.Dr.-Ing. **Alexander Rosemann**, Eindhoven University of Technology, Lighthouse Project 2015



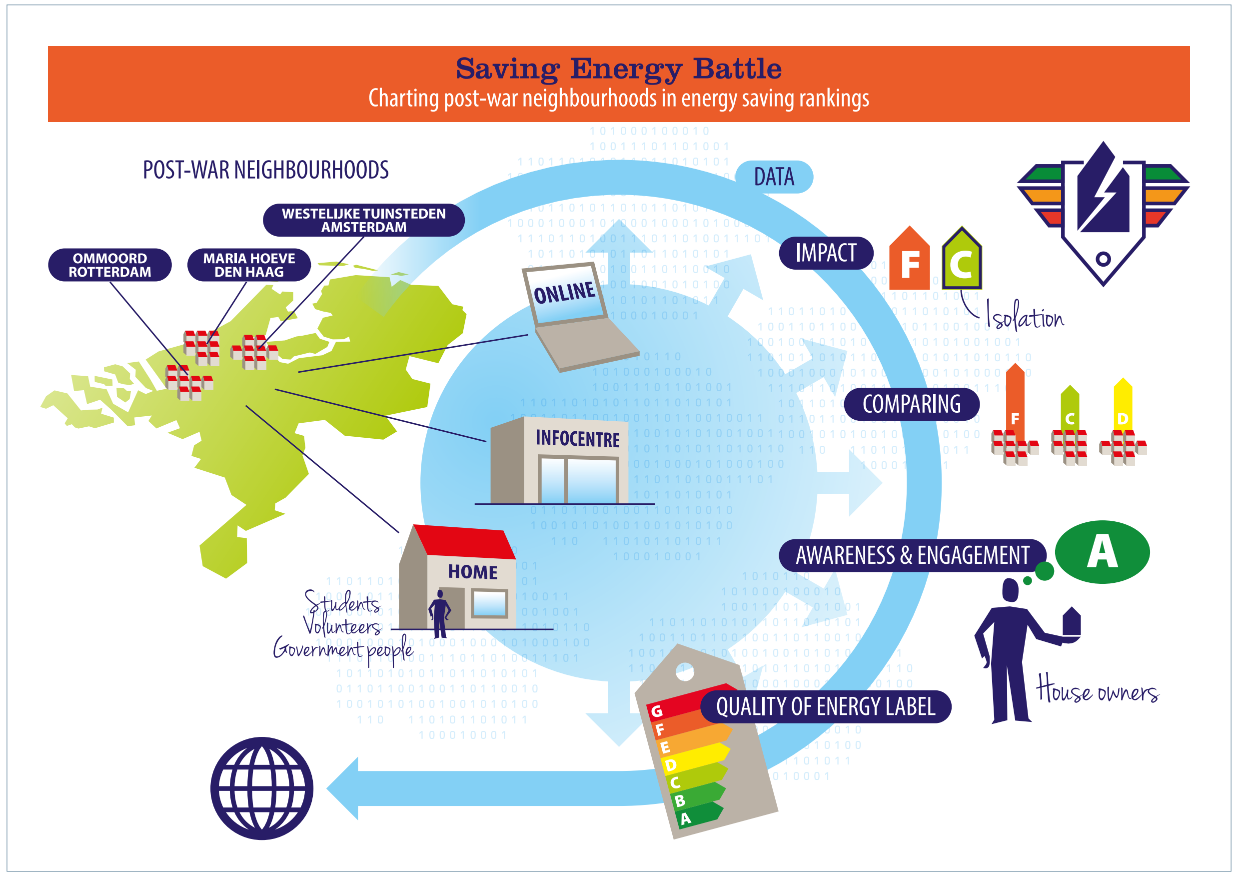
Ir. **Eric van den Ham**, Delft University of Technology, Lighthouse Project 2015



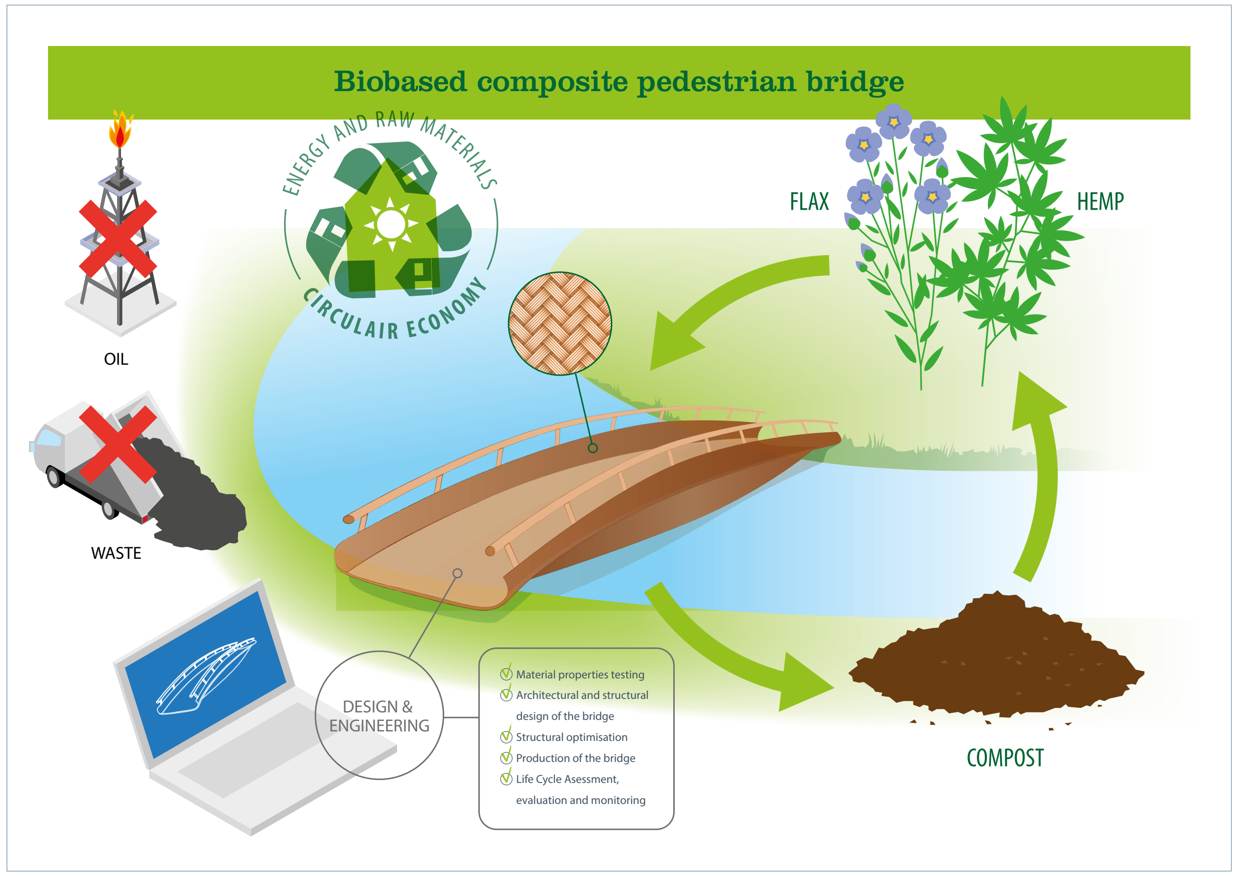
dr.ir. **Seirgei Miller**, University of Twente, Lighthouse Project 2015



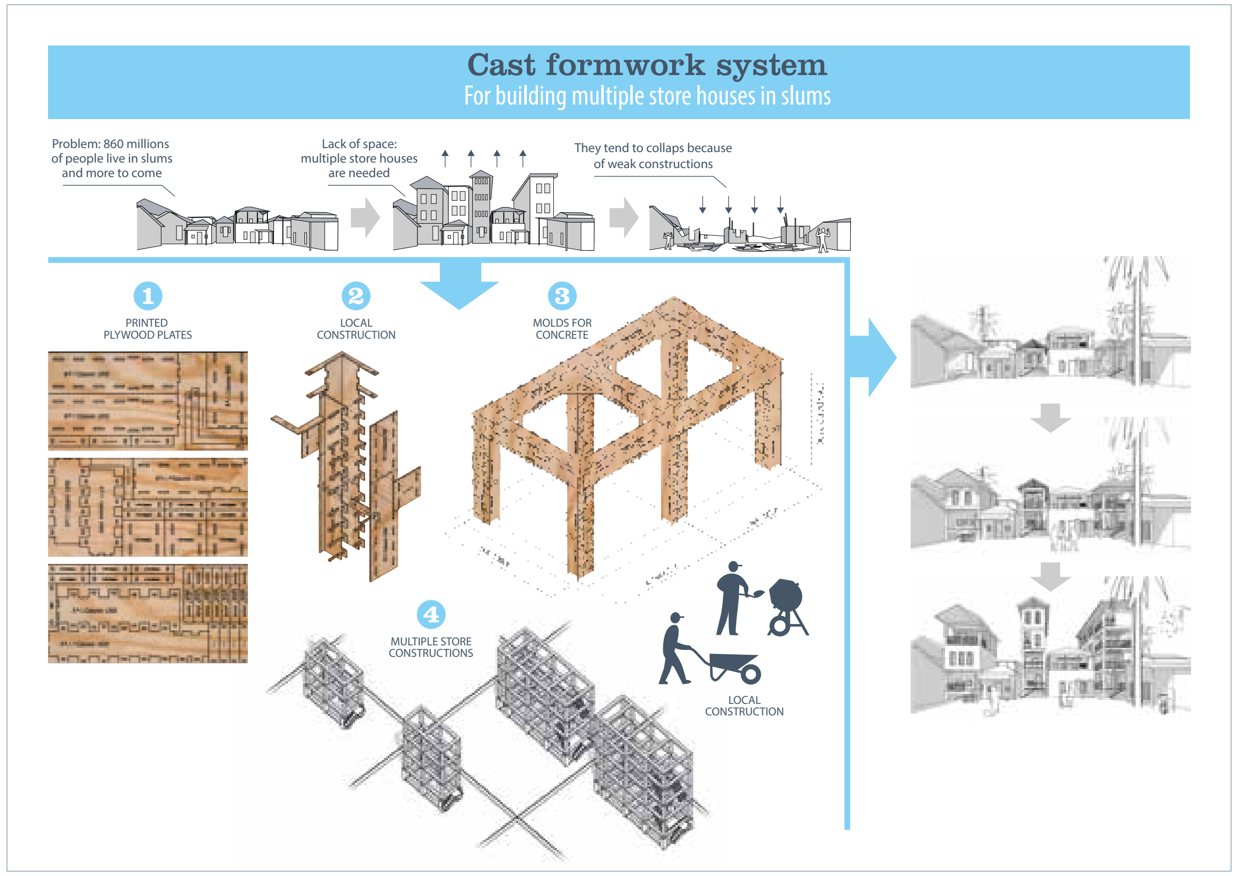
dr.ir. **Bram Entrop**, University of Twente, Lighthouse Project 2015



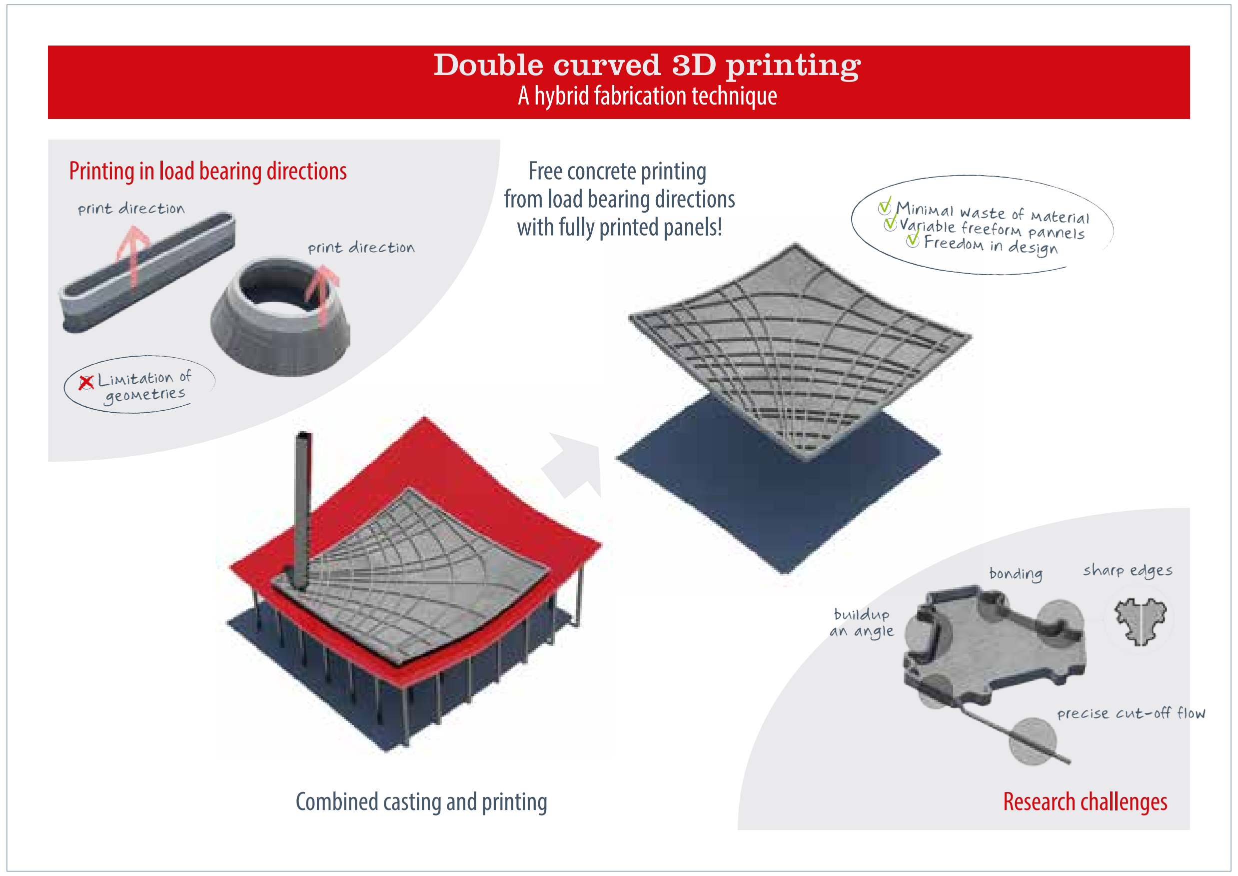
dr. **Ana Pereira Roders**, Eindhoven University of Technology, Lighthouse Project 2015



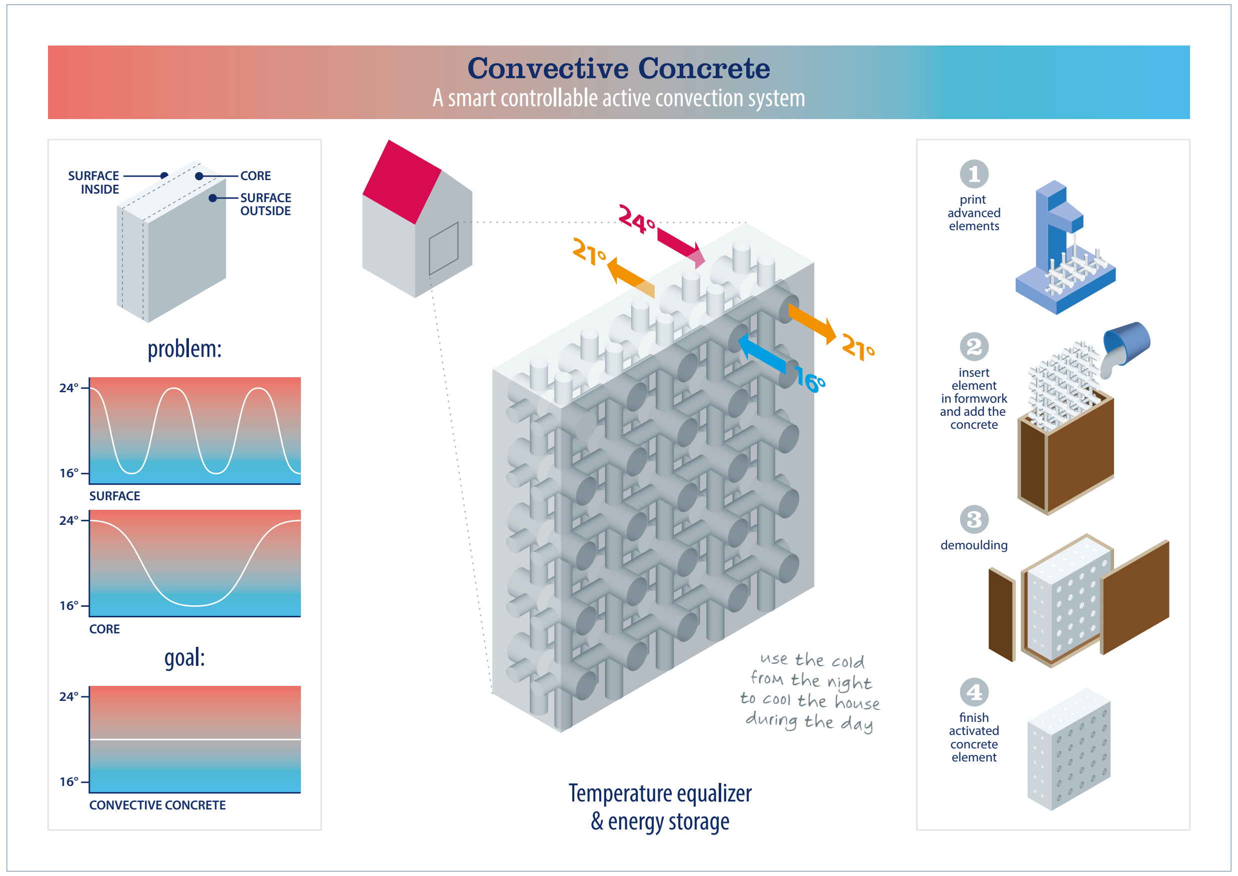
ir. **Rijk Blok**, Eindhoven University of Technology, Lighthouse Project 2016



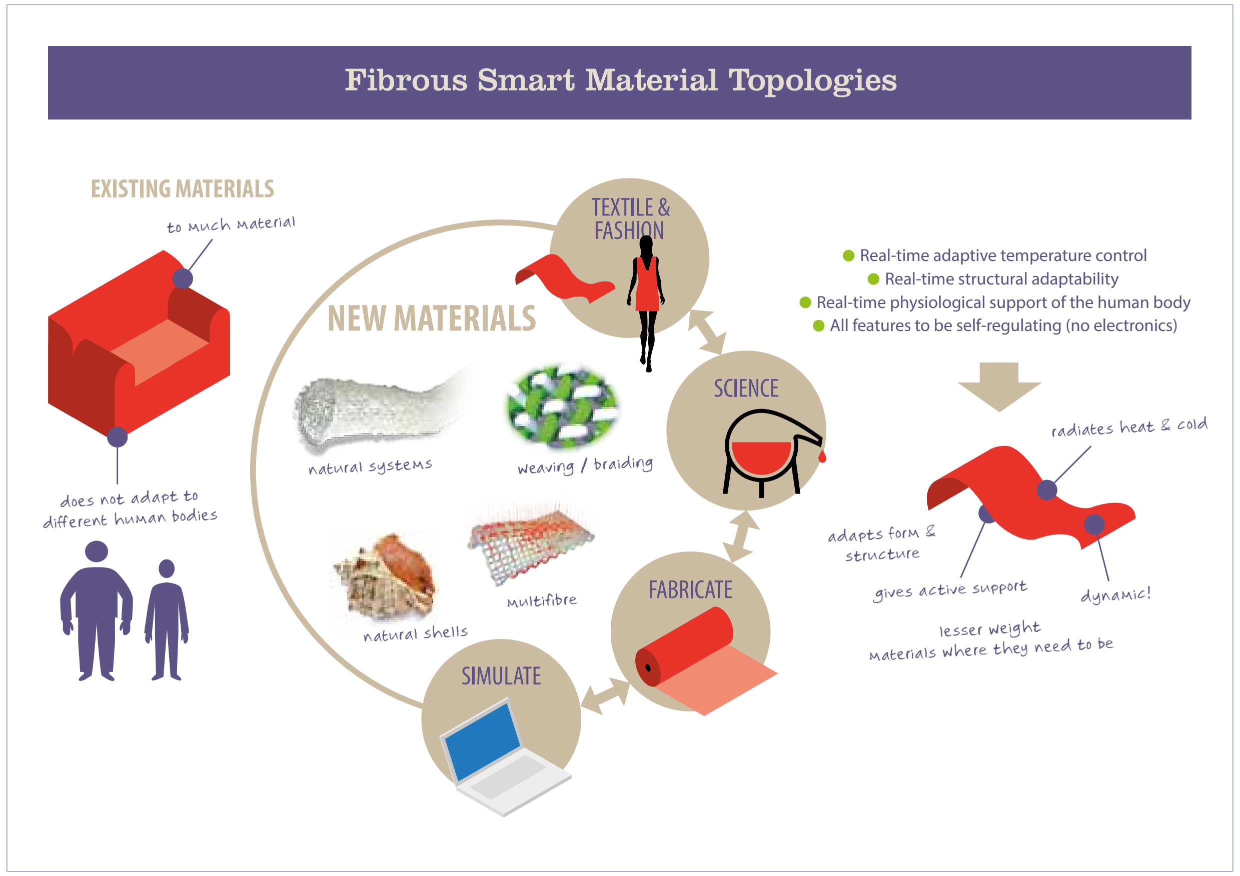
ir. **Nadia Remmerswaal**, Delft University of Technology, Lighthouse Project 2016



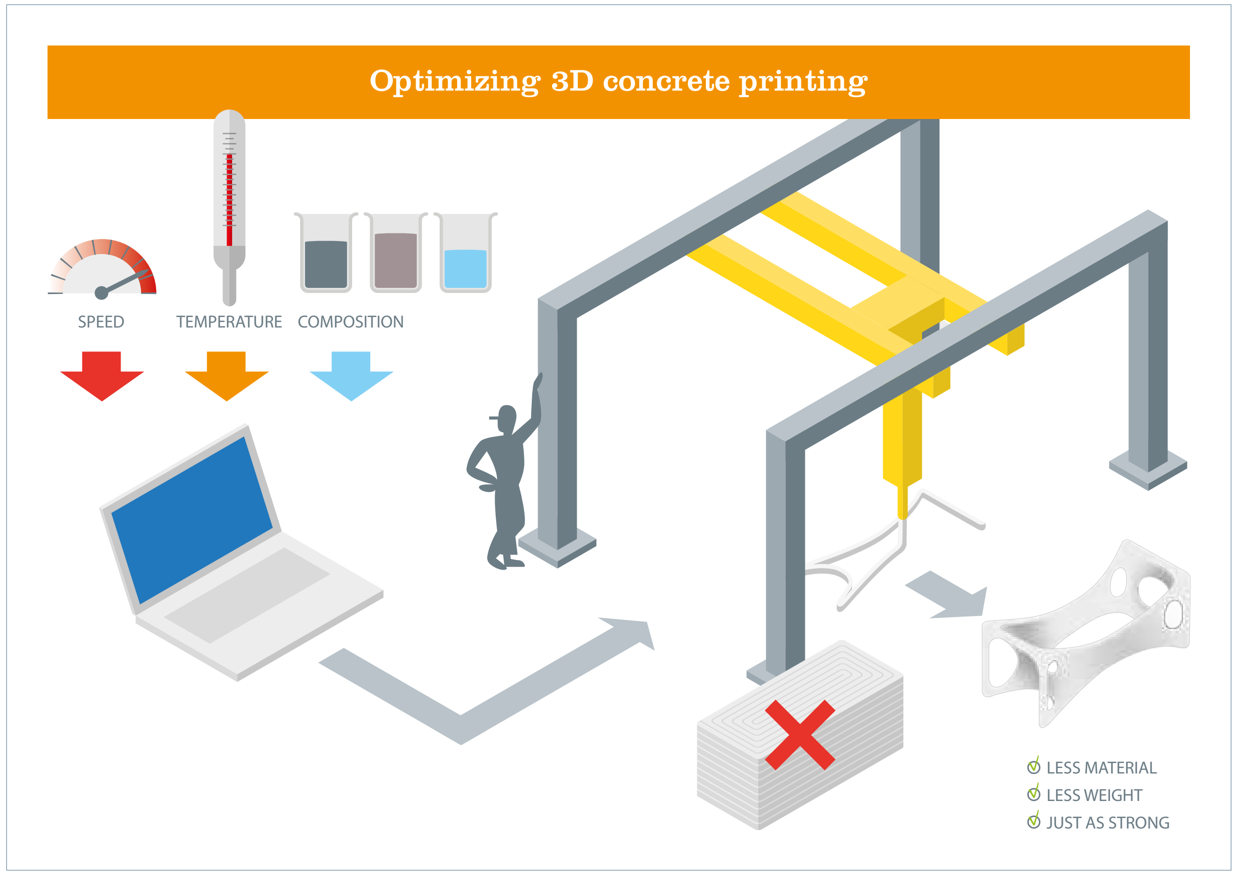
dr.ir. **Roel Schipper**, Delft University of Technology, Lighthouse Project 2016



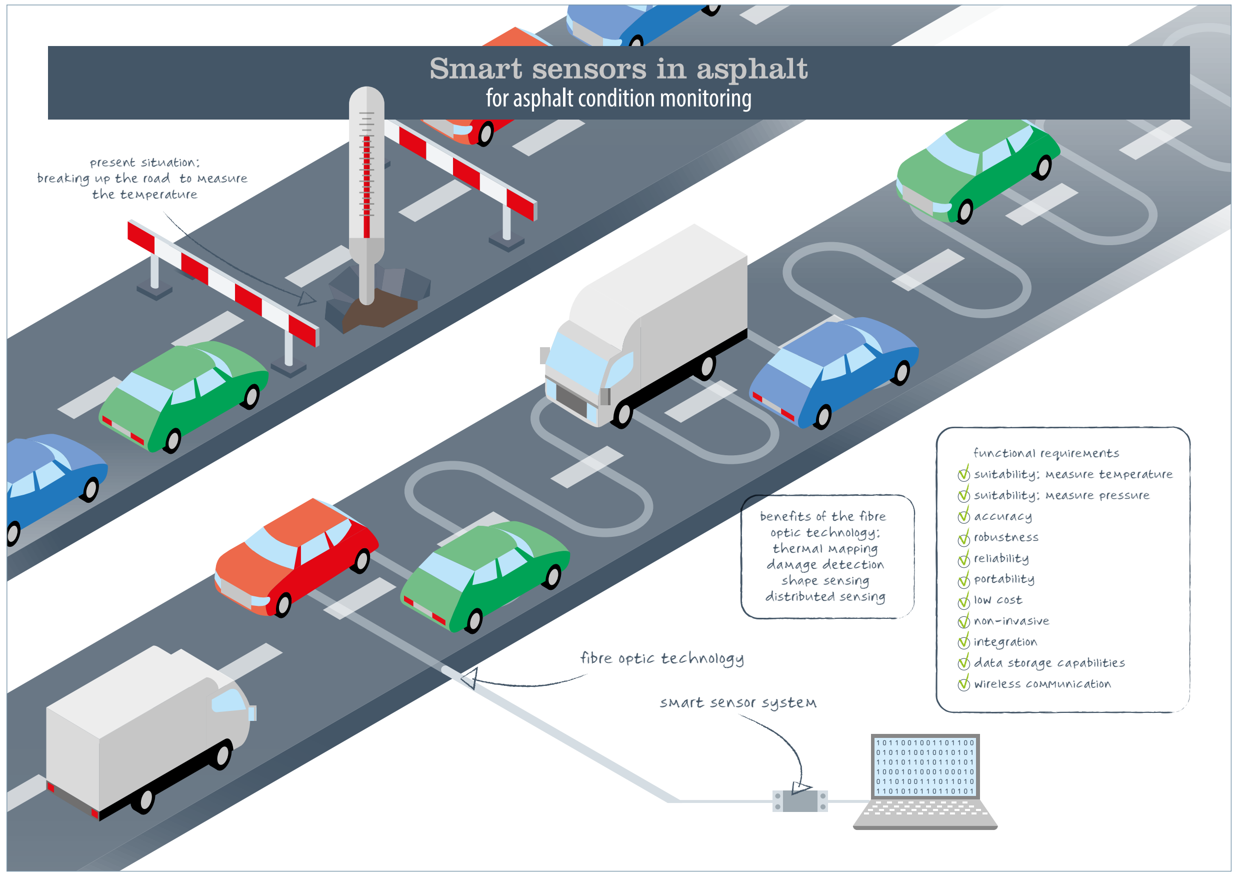
Dennis de Witte MSc., Delft University of Technology, Lighthouse Project 2016



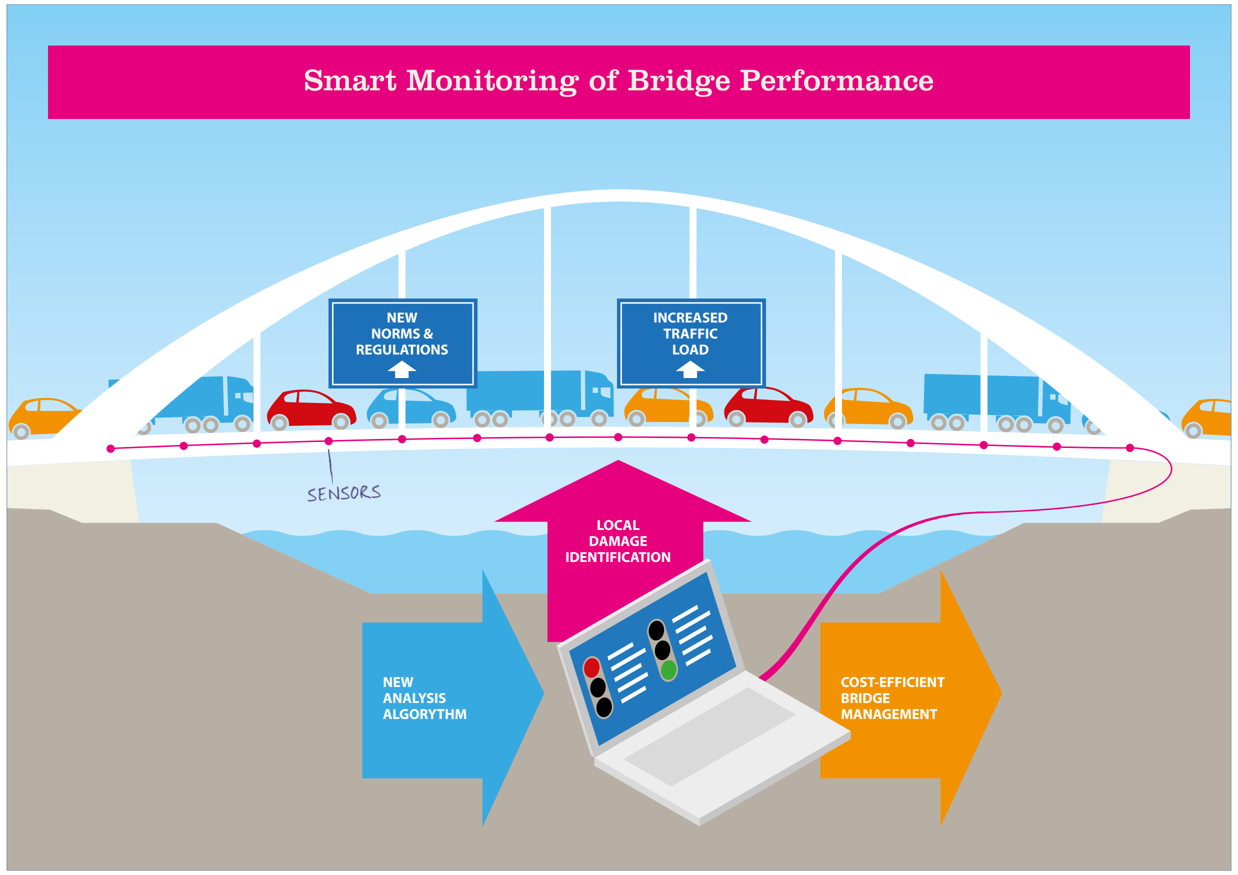
dr. **Nimish Biloria**, Delft University of Technology, Lighthouse Project 2016



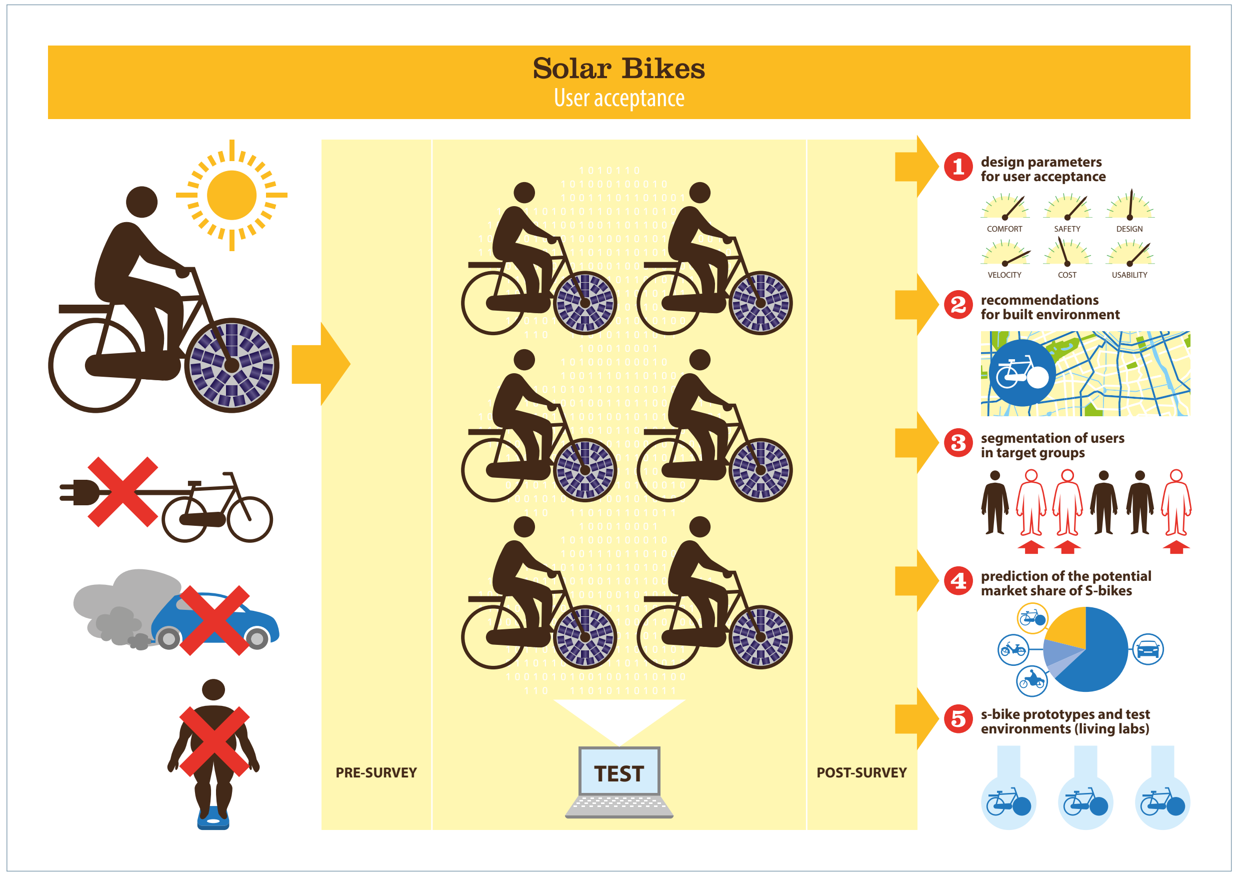
dr.ir. **Jeroen Coenders**, Delft University of Technology, Lighthouse Project 2016



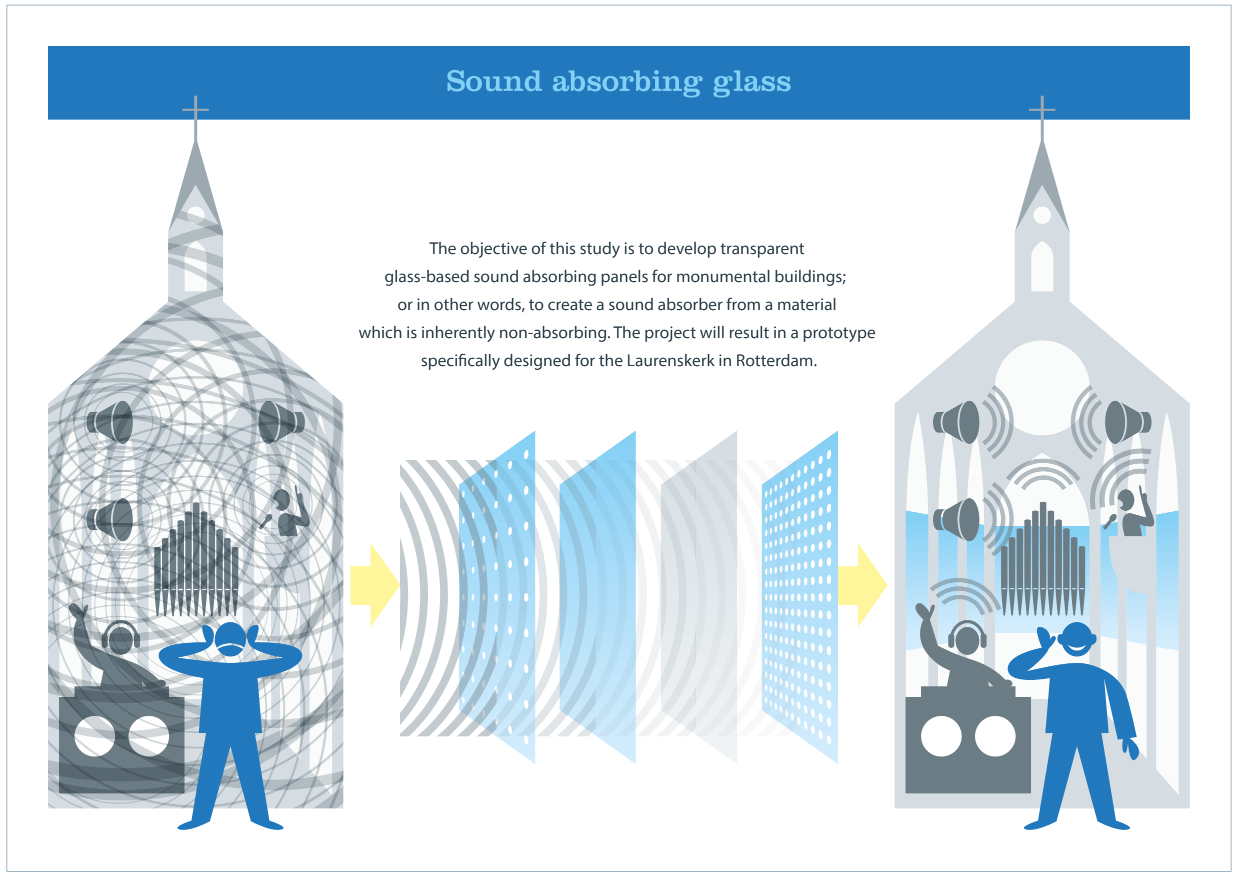
dr.ir. **Seirgei Miller**, University of Technology, Lighthouse Project 2016



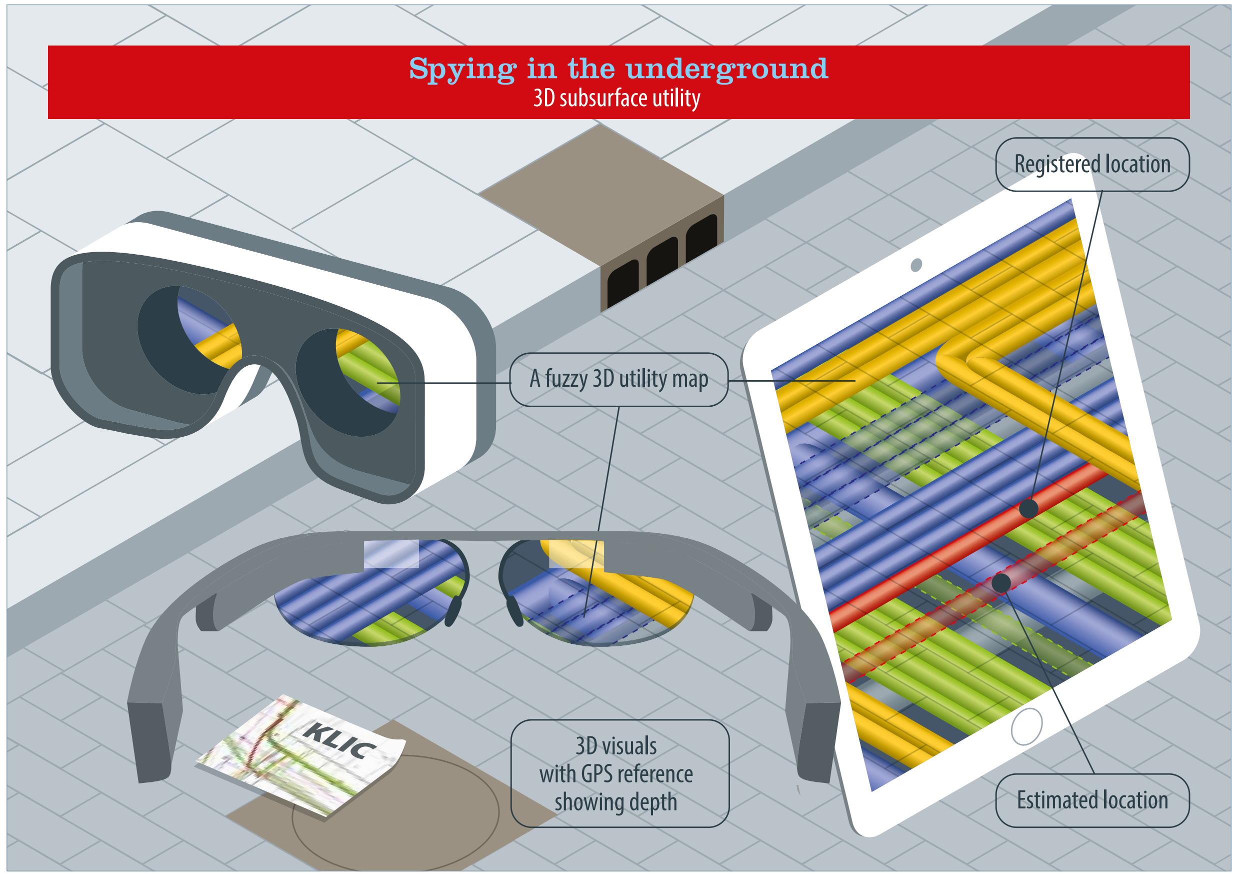
dr. **Andreas Hartmann**, University of Twente, Lighthouse Project 2016



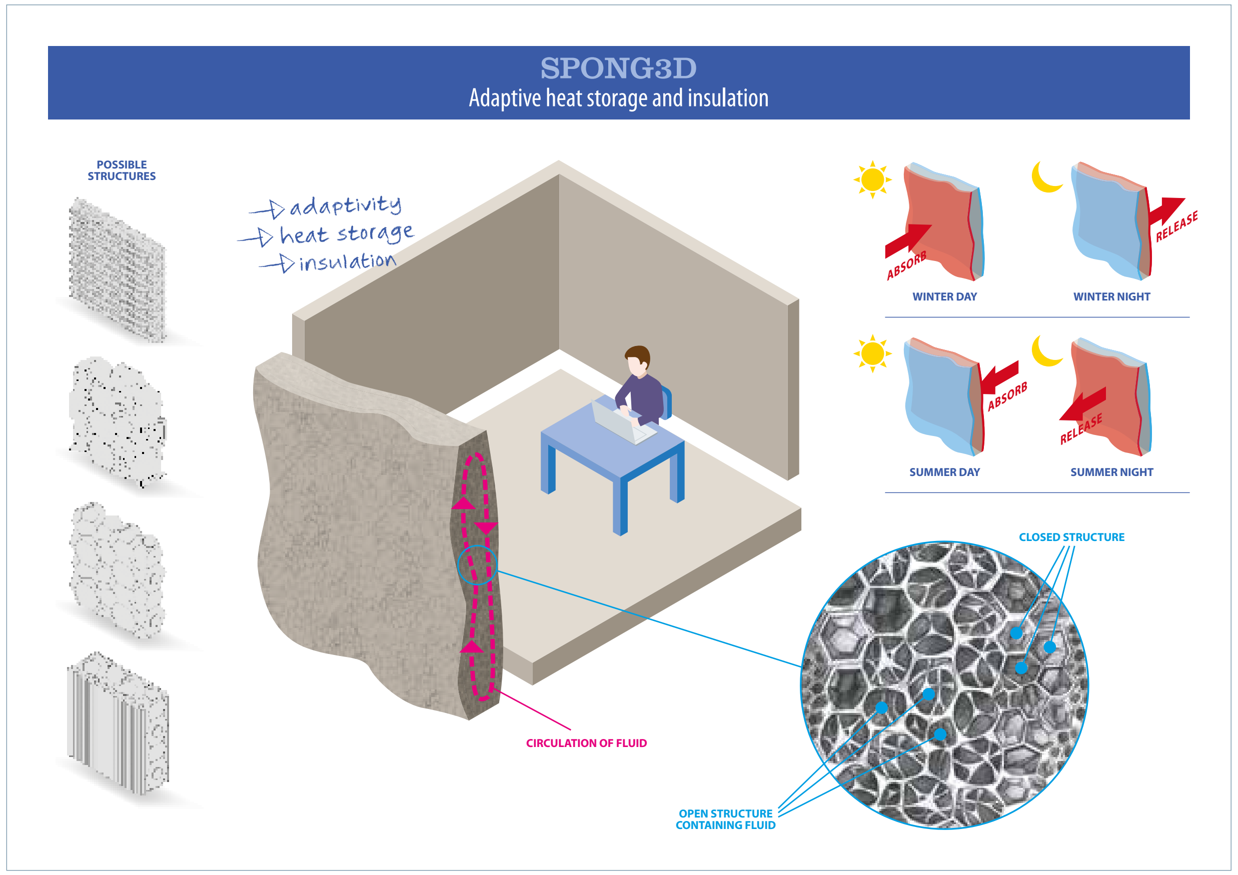
dr.ir. **Pauline van den Berg**, Eindhoven University of Technology, Lighthouse Project 2016



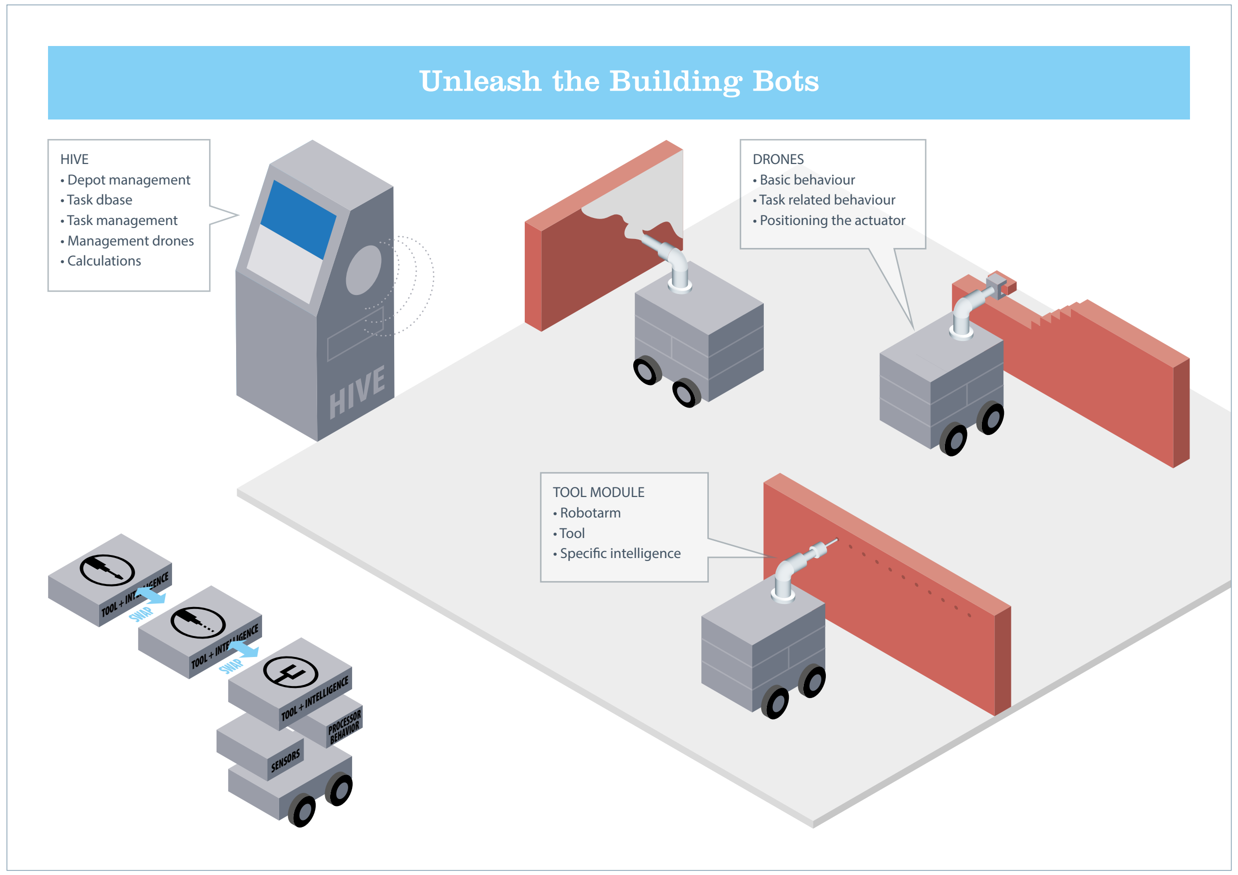
ir. **Anne Struiksma**, Delft University of Technology, Lighthouse Project 2016



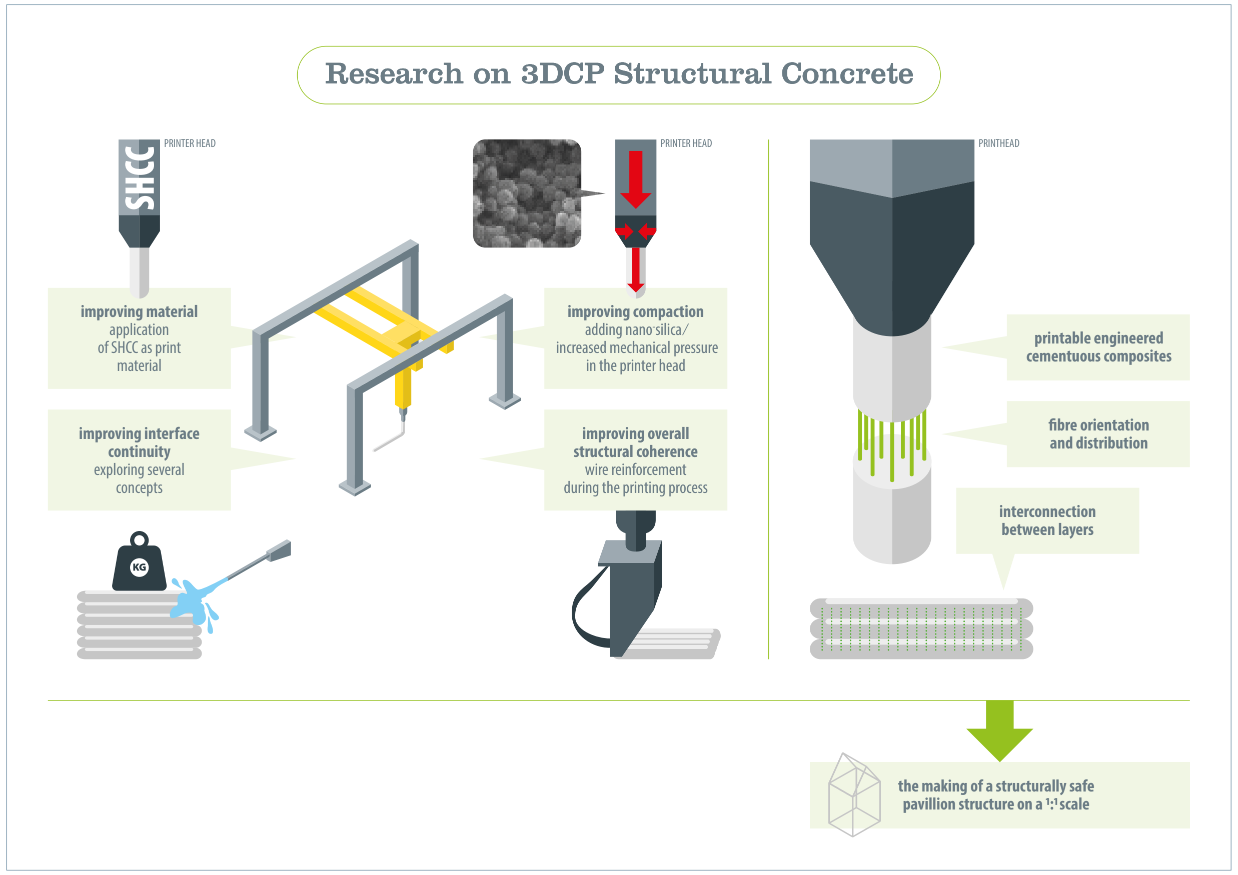
dr.ir. **Léon olde Scholtenhuis**, University of Twente, Lighthouse Project 2016



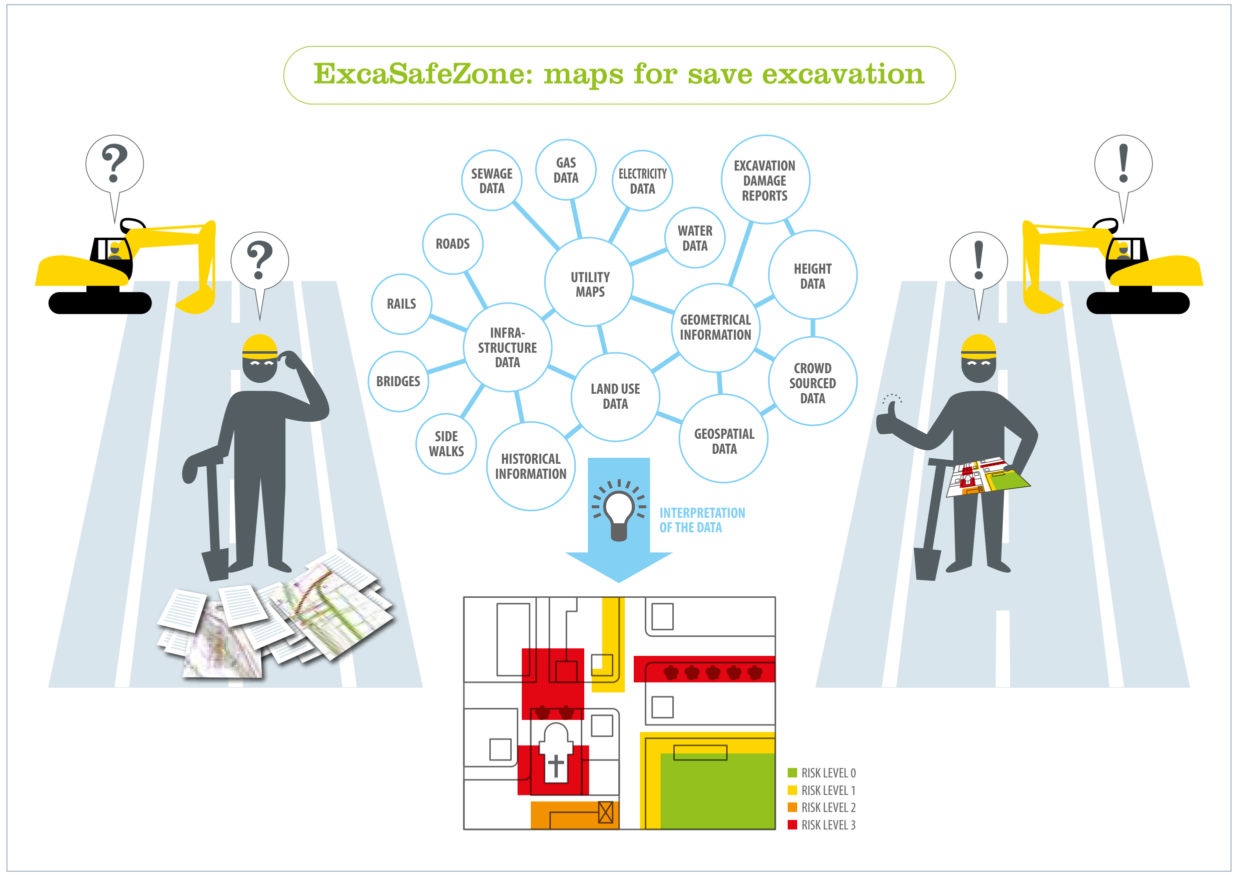
ing. **Maria Valentini Sarakinioti**, Delft University of Technology, Lighthouse Project 2016



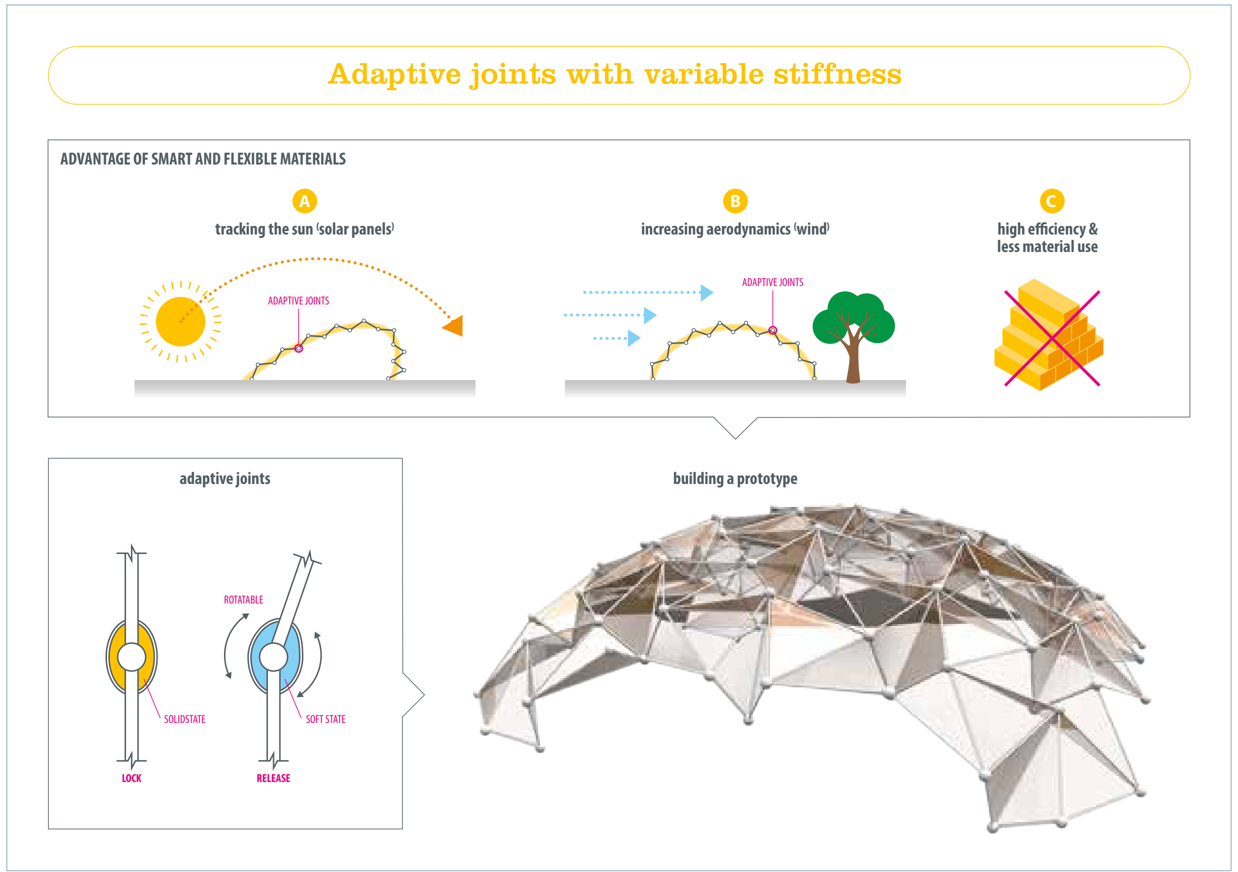
Aant van der Zee, Eindhoven University of Technology, Lighthouse Project 2016



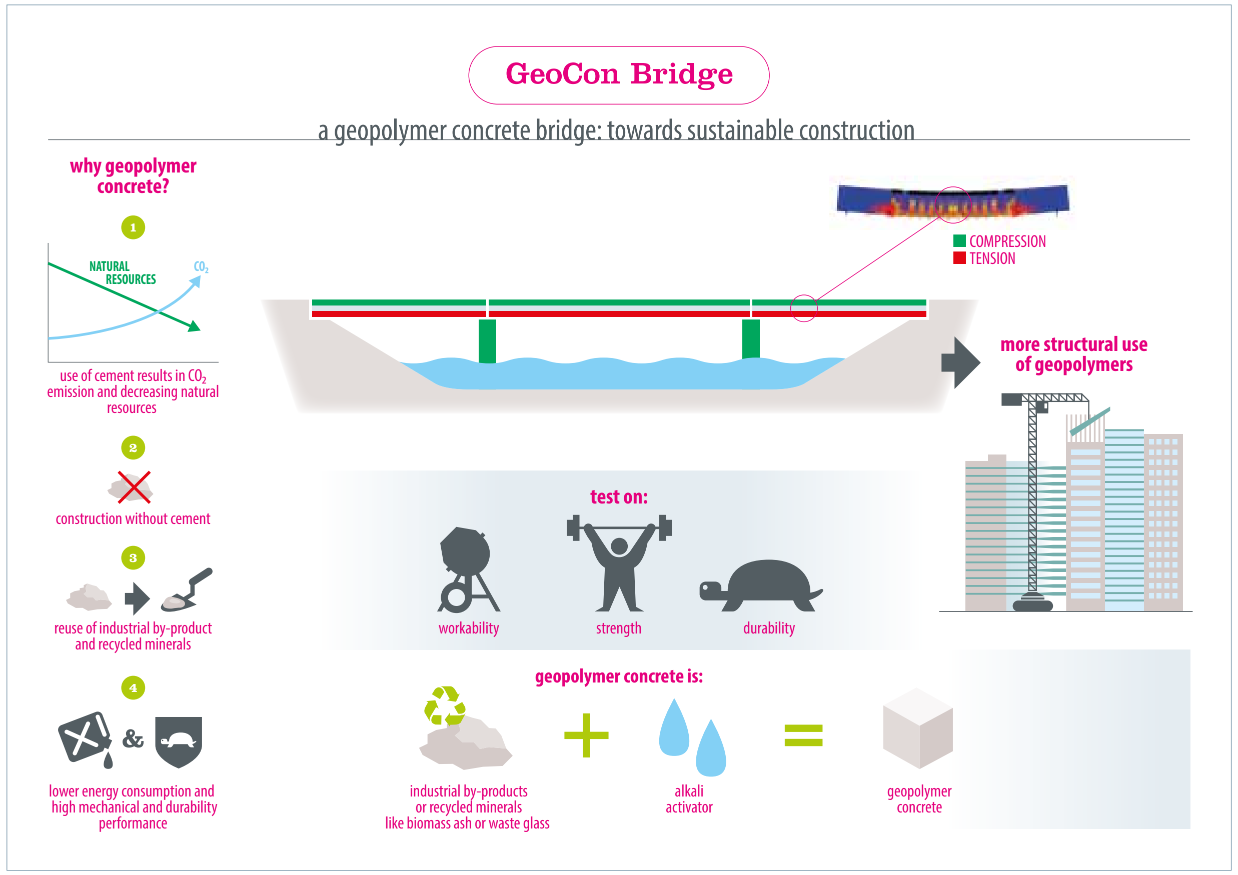
dr.ir. **Freek Bos**, Eindhoven University of Technology, Lighthouse Project 2017



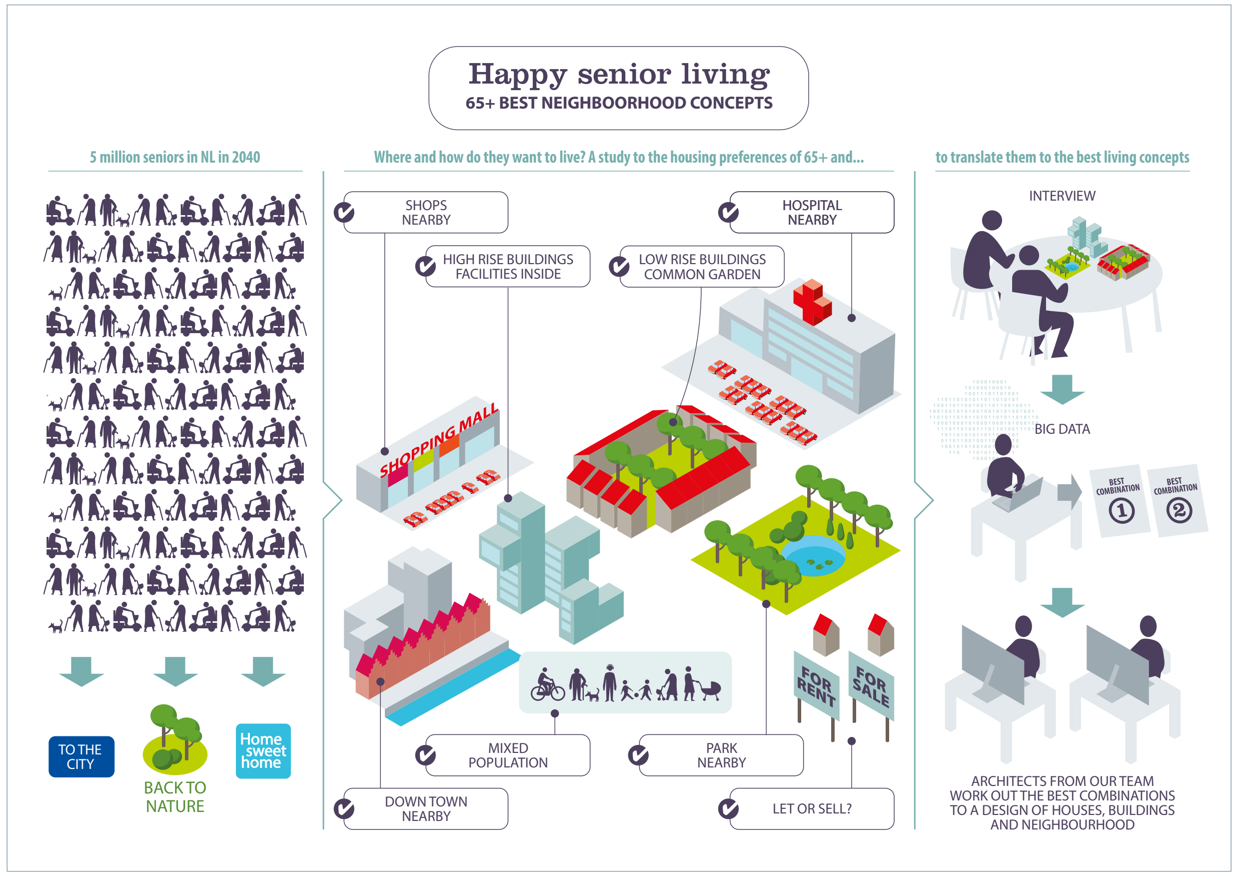
dr.ir. **Léon olde Scholtenhuis**, University of Twente, Lighthouse Project 2017



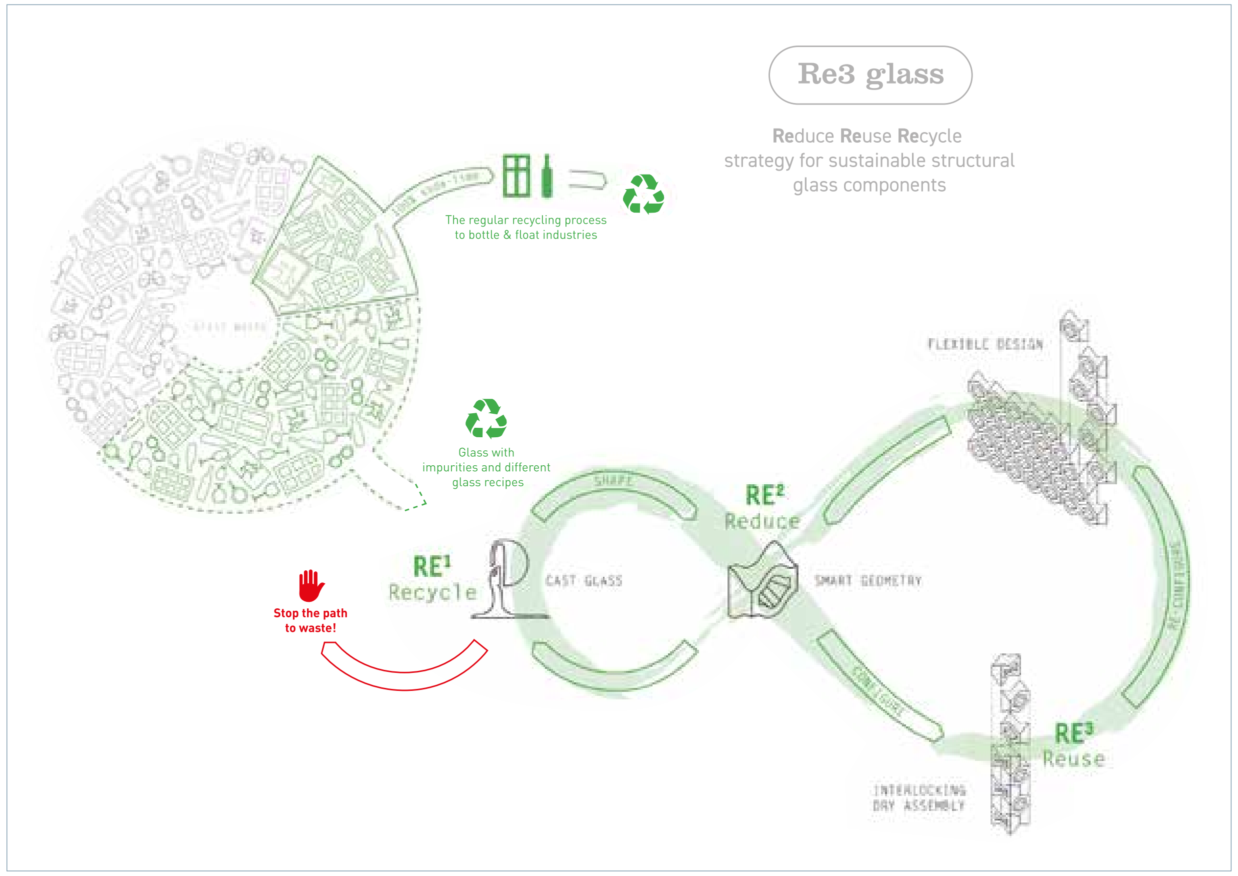
ir. **Qinyu Wang**, Eindhoven University of Technology, Lighthouse Project 2017



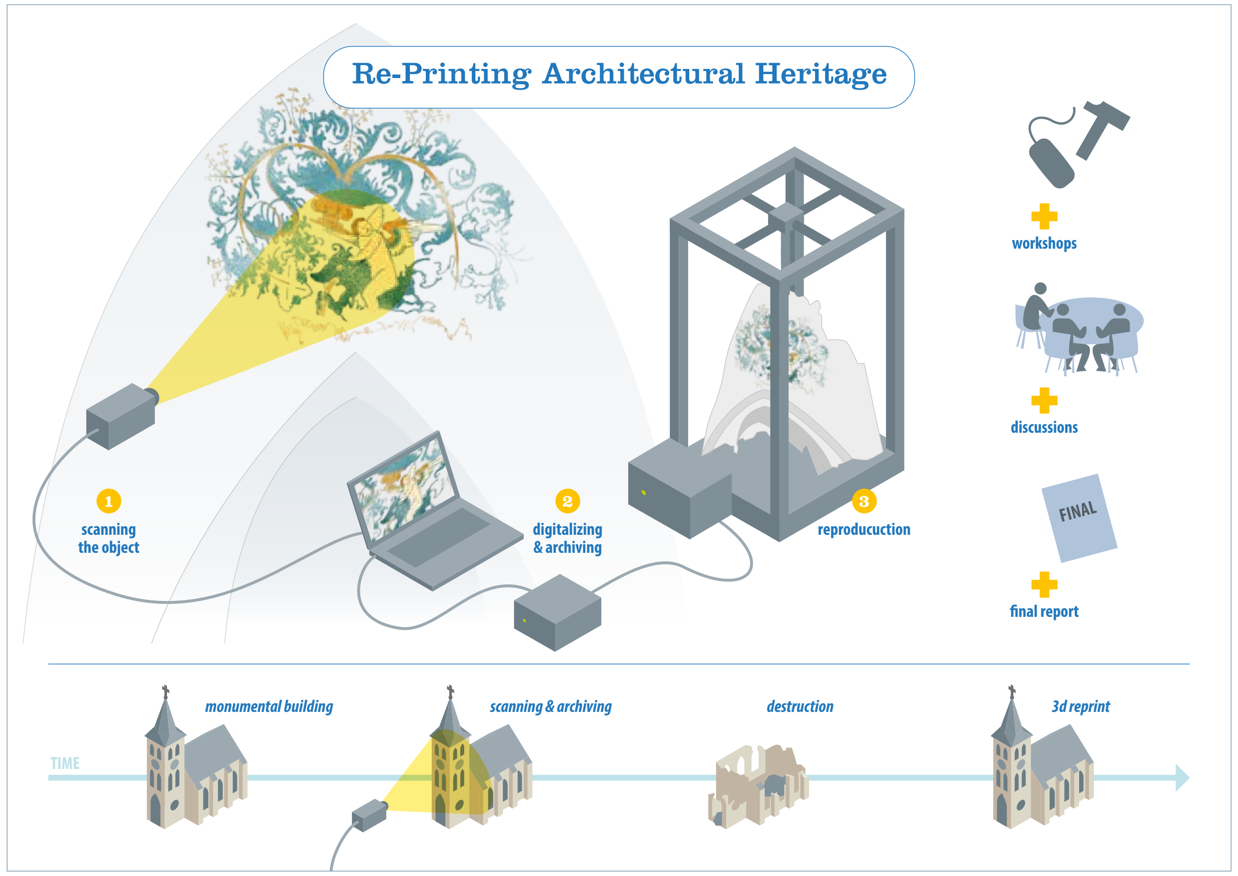
dr. **Guang Ye**, Delft University of Technology, Lighthouse Project 2017



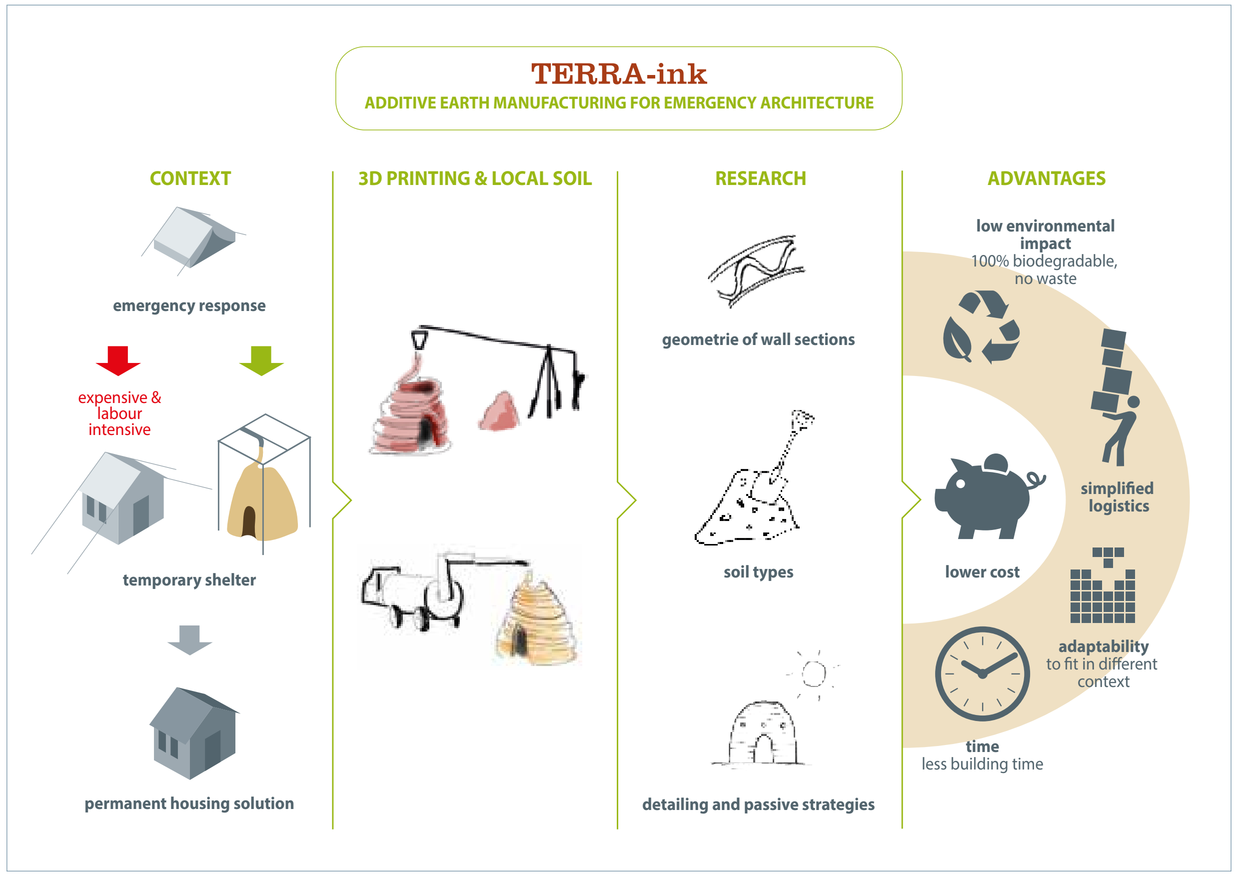
dr. **Ioulia Ossokina**, Eindhoven University of Technology, Lighthouse Project 2017



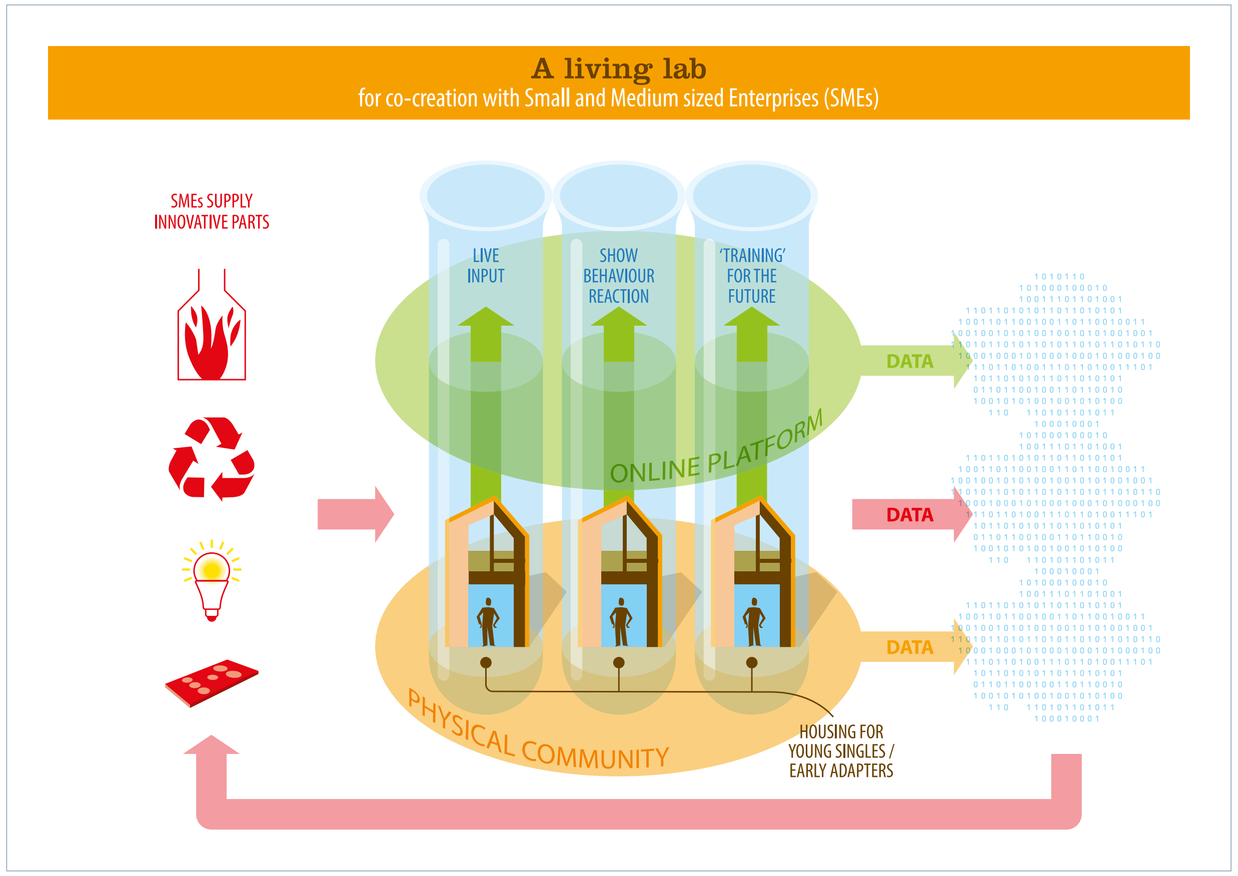
ir. **Telesilla Bristogianni**, ir. **Faidra Oikonomopoulou**, Delft University of Technology, Lighthouse Project 2017



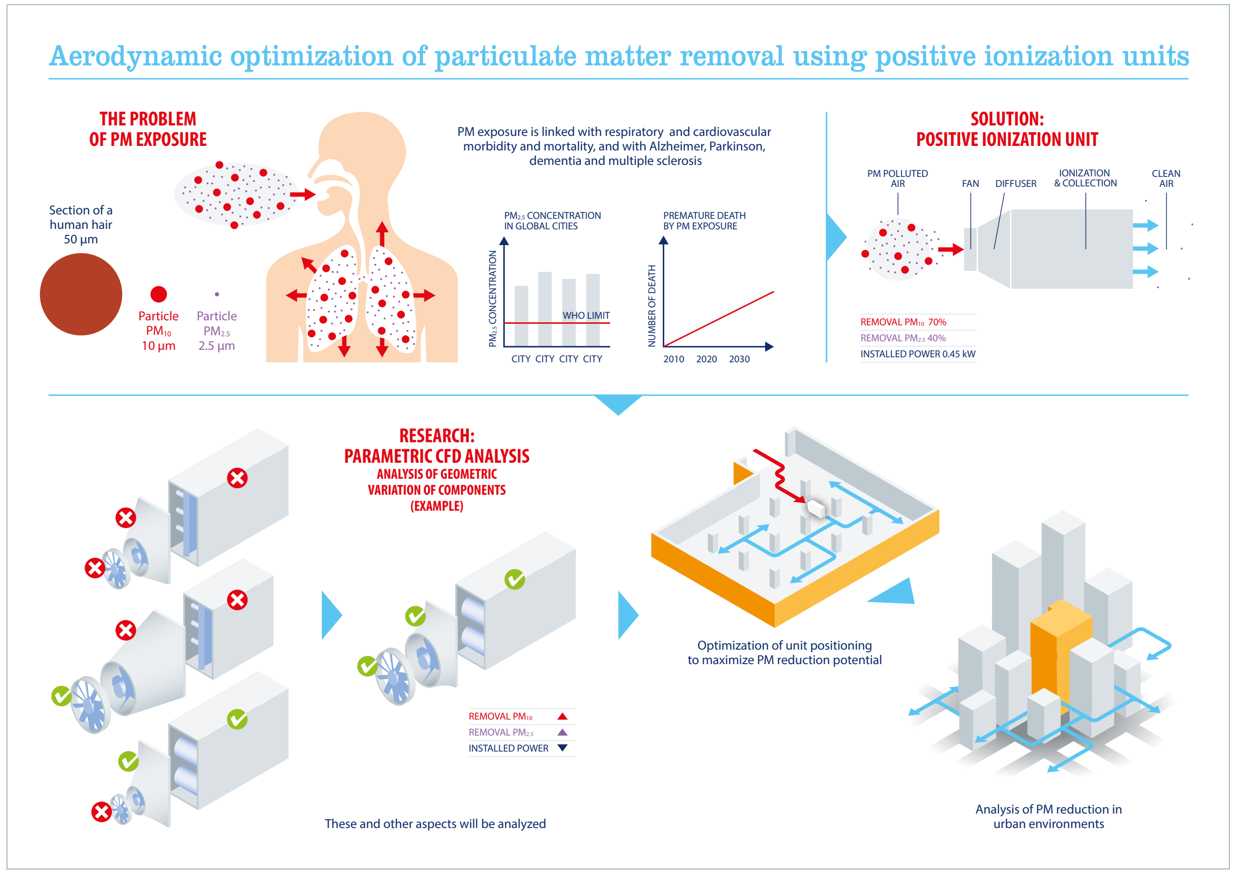
prof.dr.ir. **Carola Hein**, Delft University of Technology, Lighthouse Project 2017



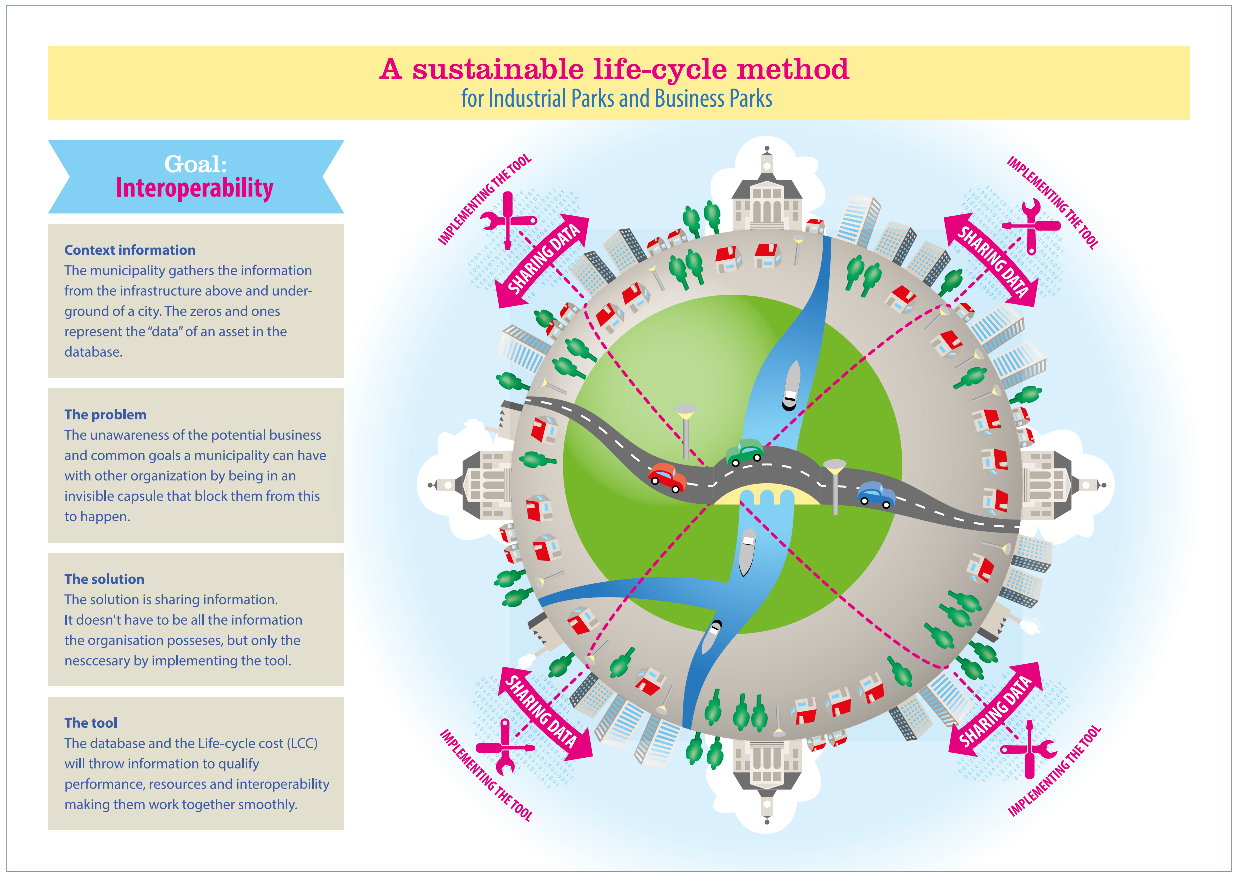
Tommaso Venturi, Delft University of Technology, Lighthouse Project 2017



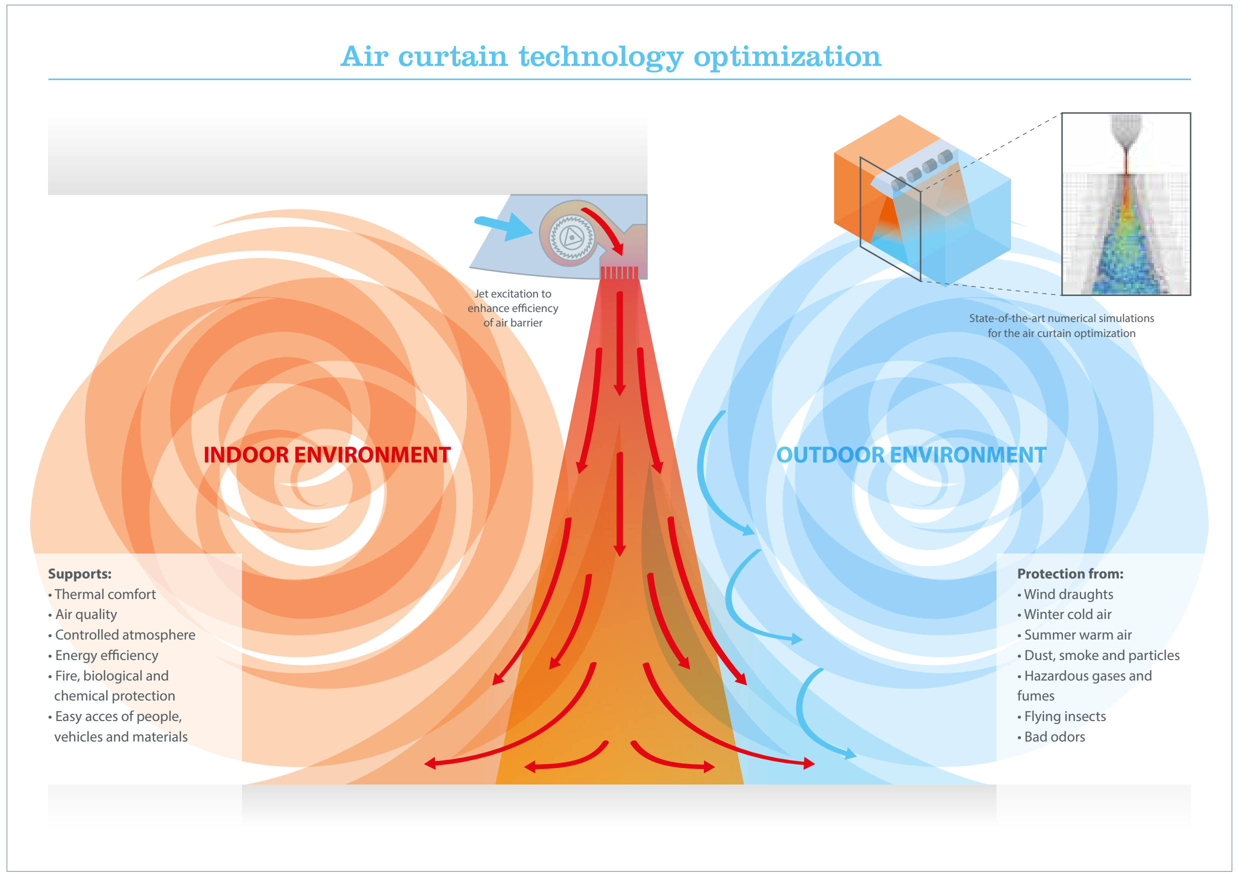
ir.MEng. **Argyrios Papadopoulos**, Eindhoven University of Technology, PDEng 2015



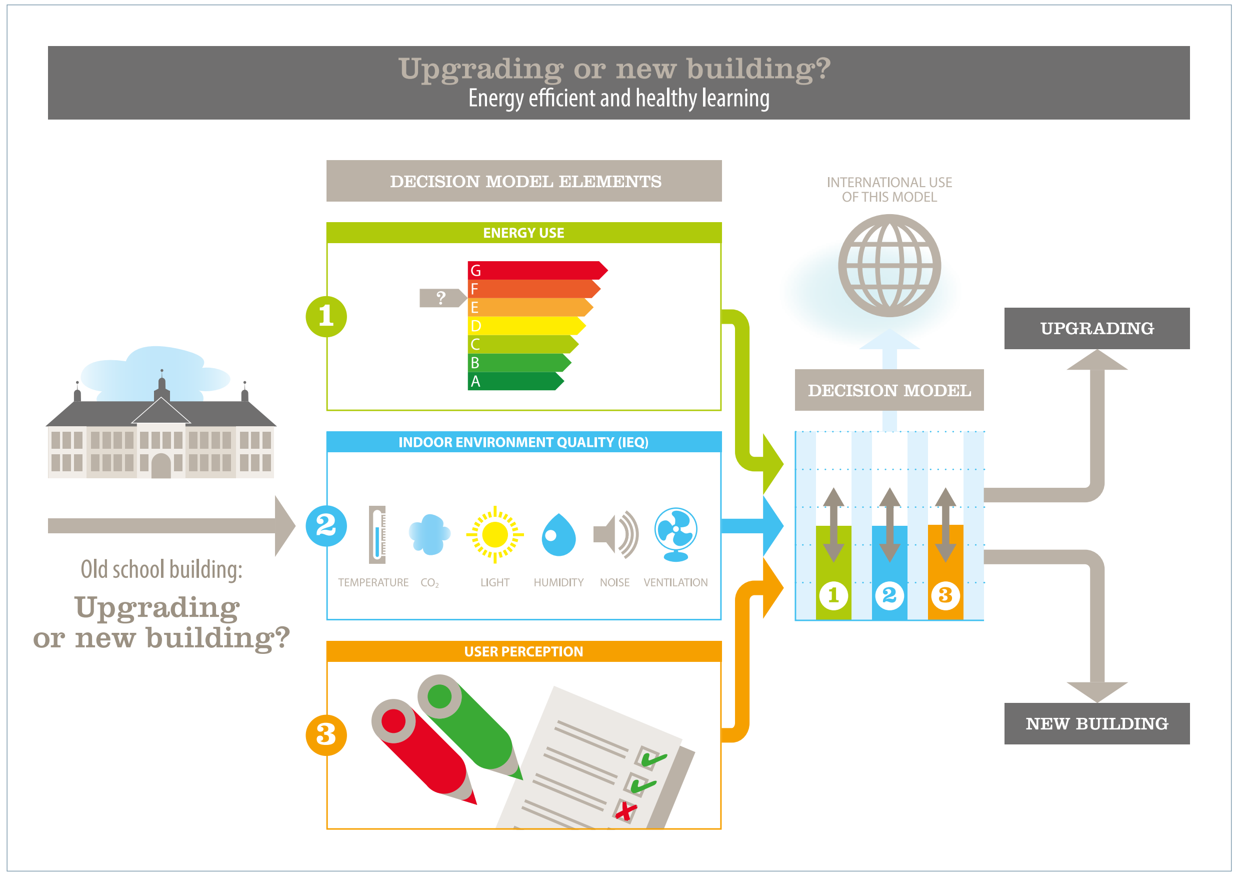
ir. **Rob Vervoort**, Eindhoven University of Technology, PDEng 2017



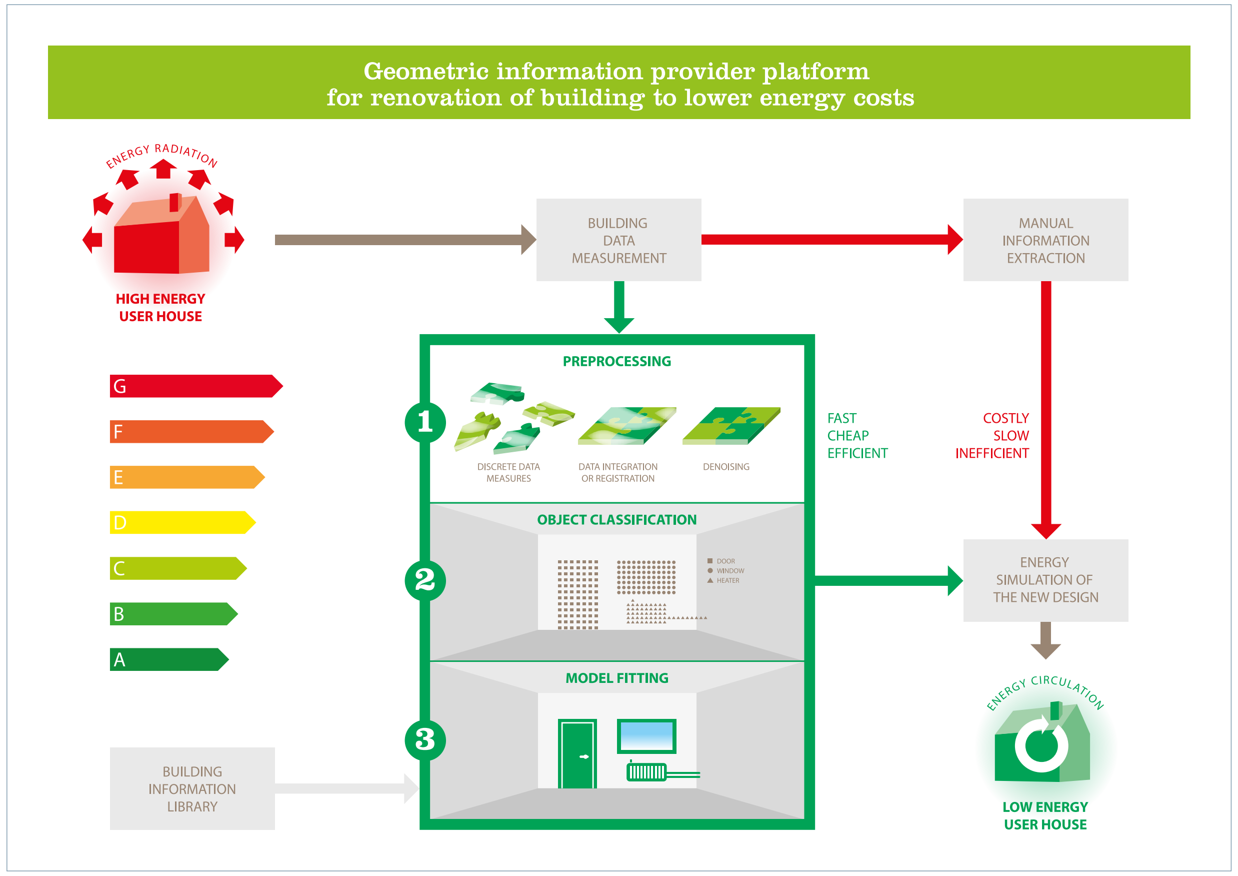
Diruij Dugarte Manoukian MSc., University of Twente, PDEng 2015



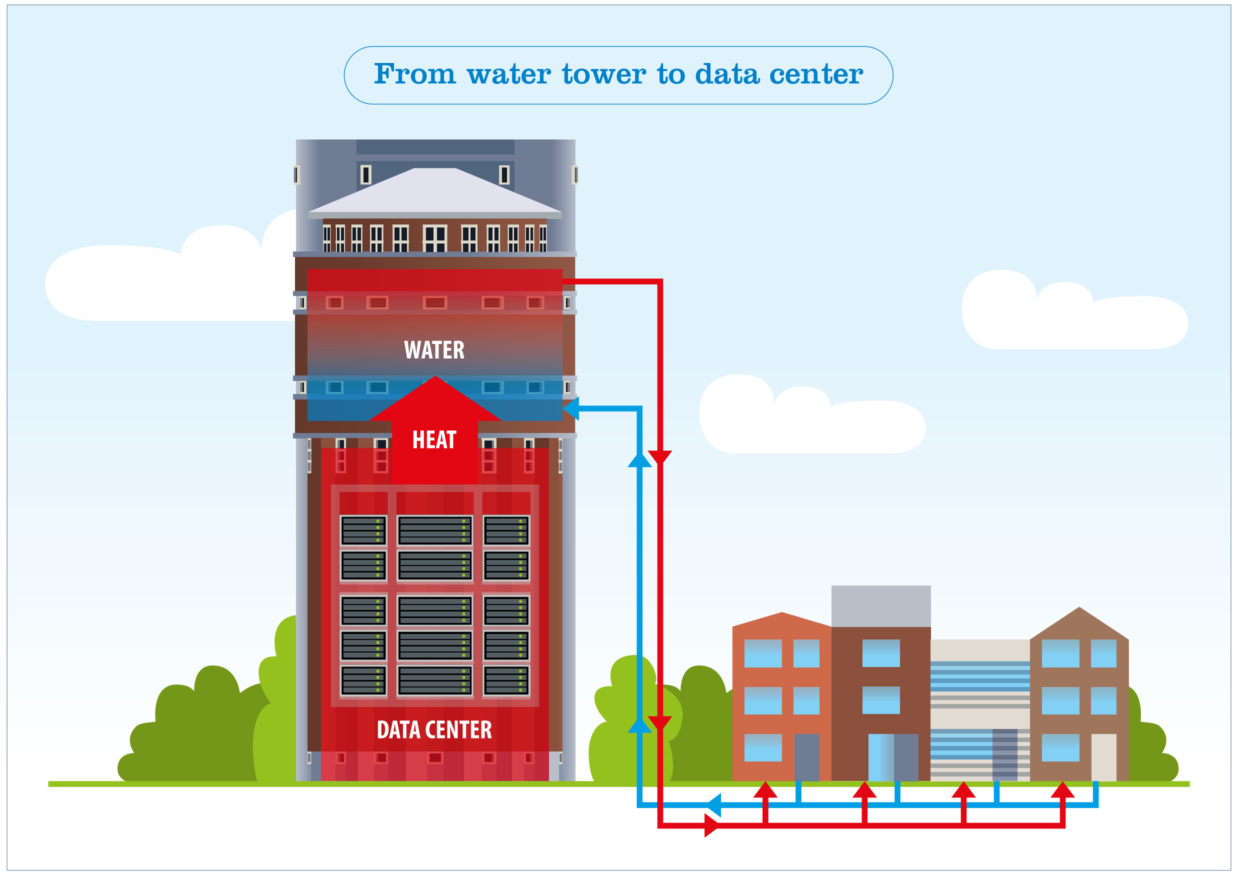
ir. **Claudio Alanis Ruiz**, Eindhoven University of Technology, PDEng 2017



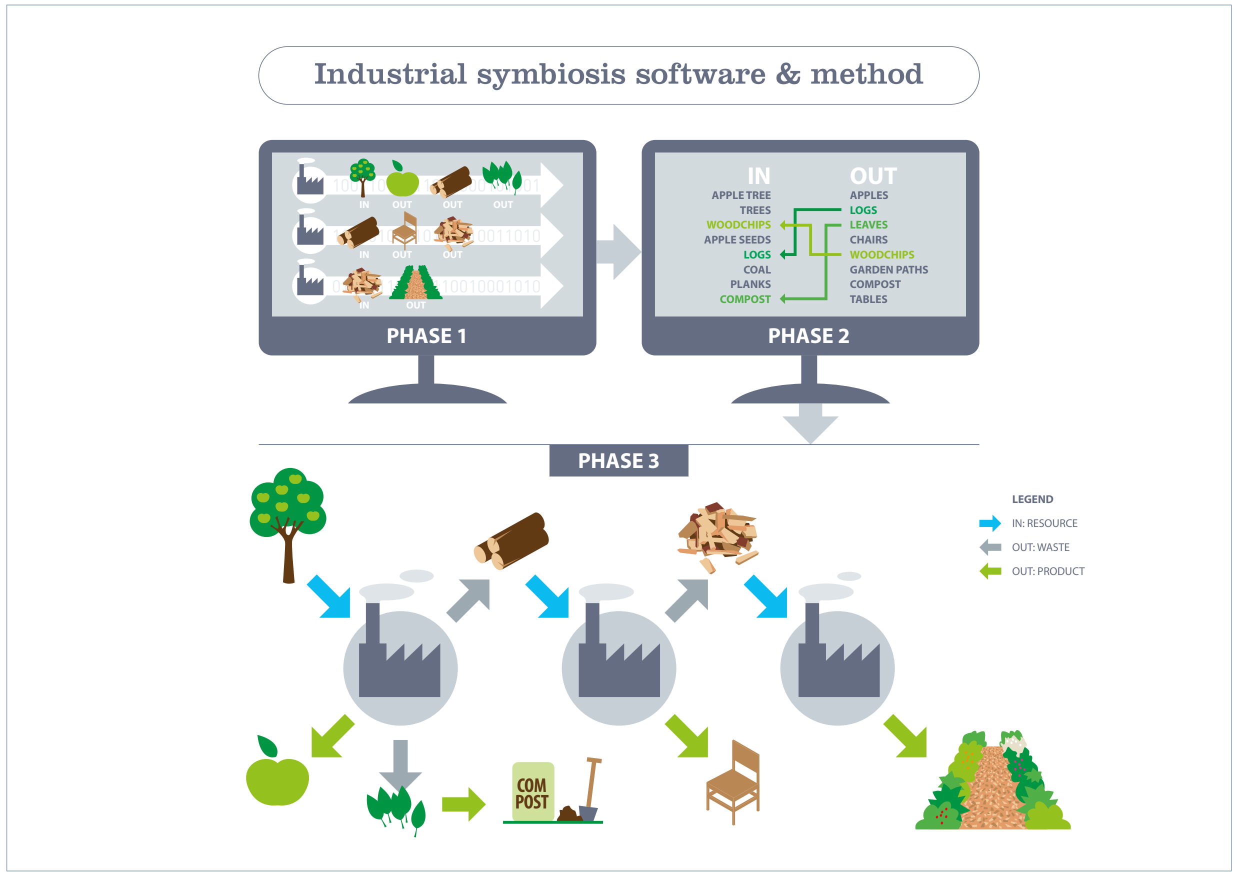
Stephanie Villegas Martinez, Eindhoven University of Technology, PDEng 2015



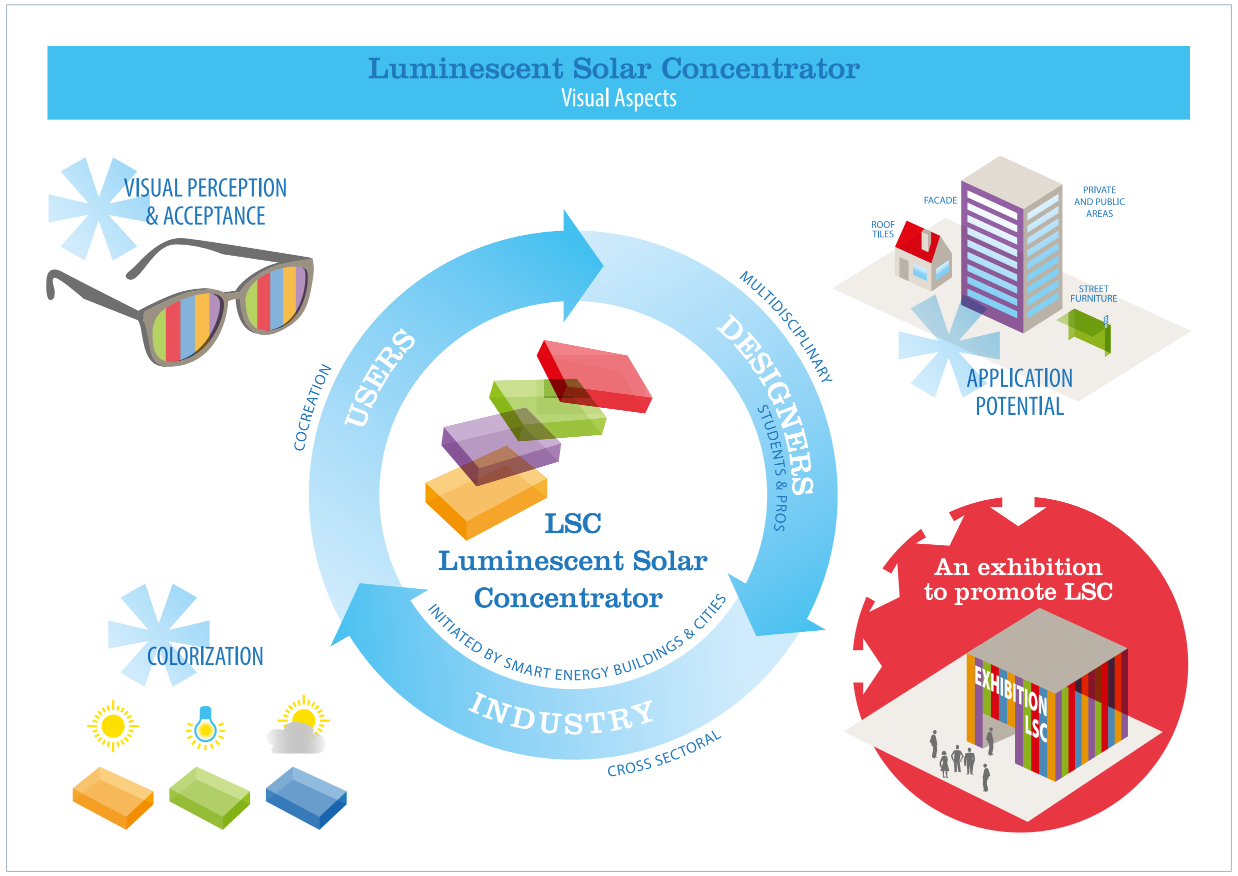
Meisam Yousefzadeh MSc., University of Twente – VISICO, PDEng 2015



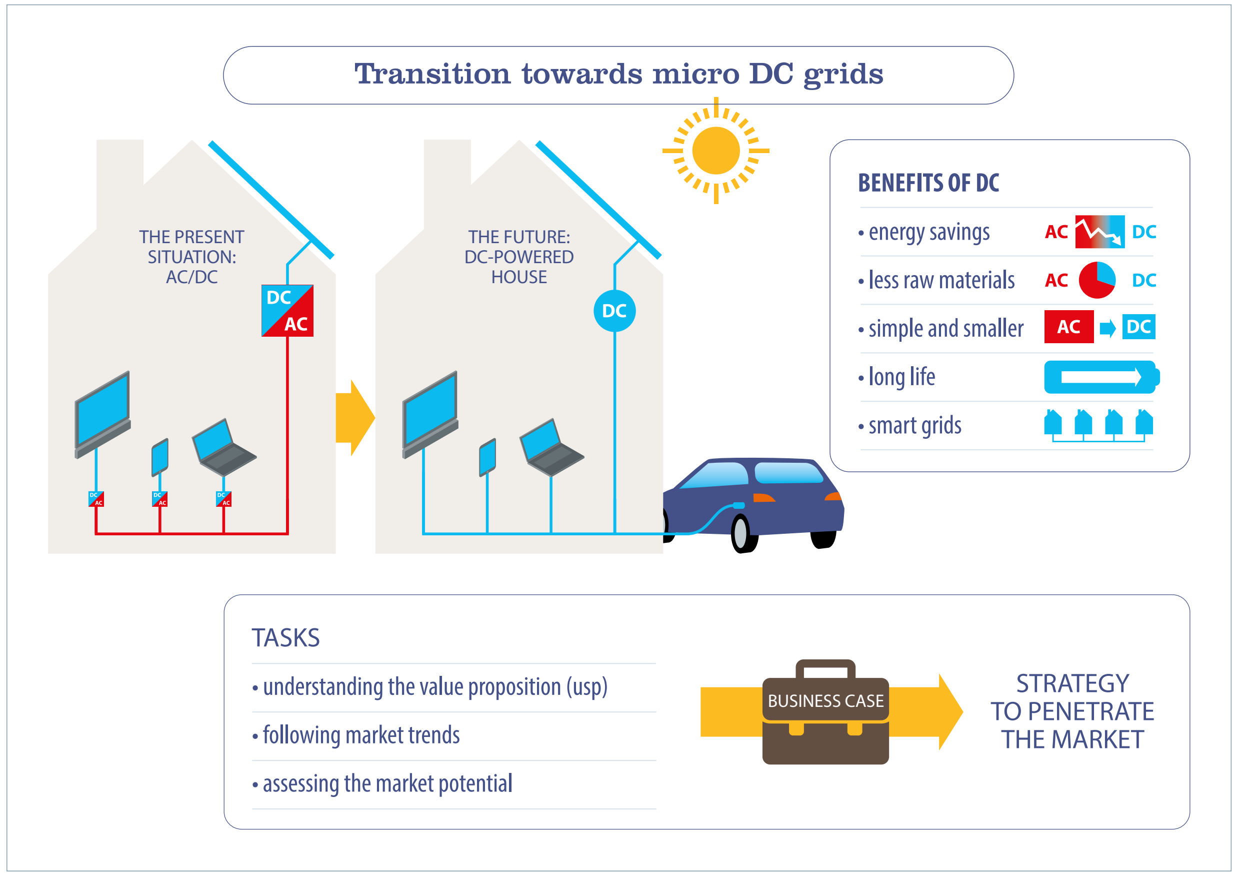
Konstantinos Tzanakakis, Eindhoven University of Technology, PDEng 2016



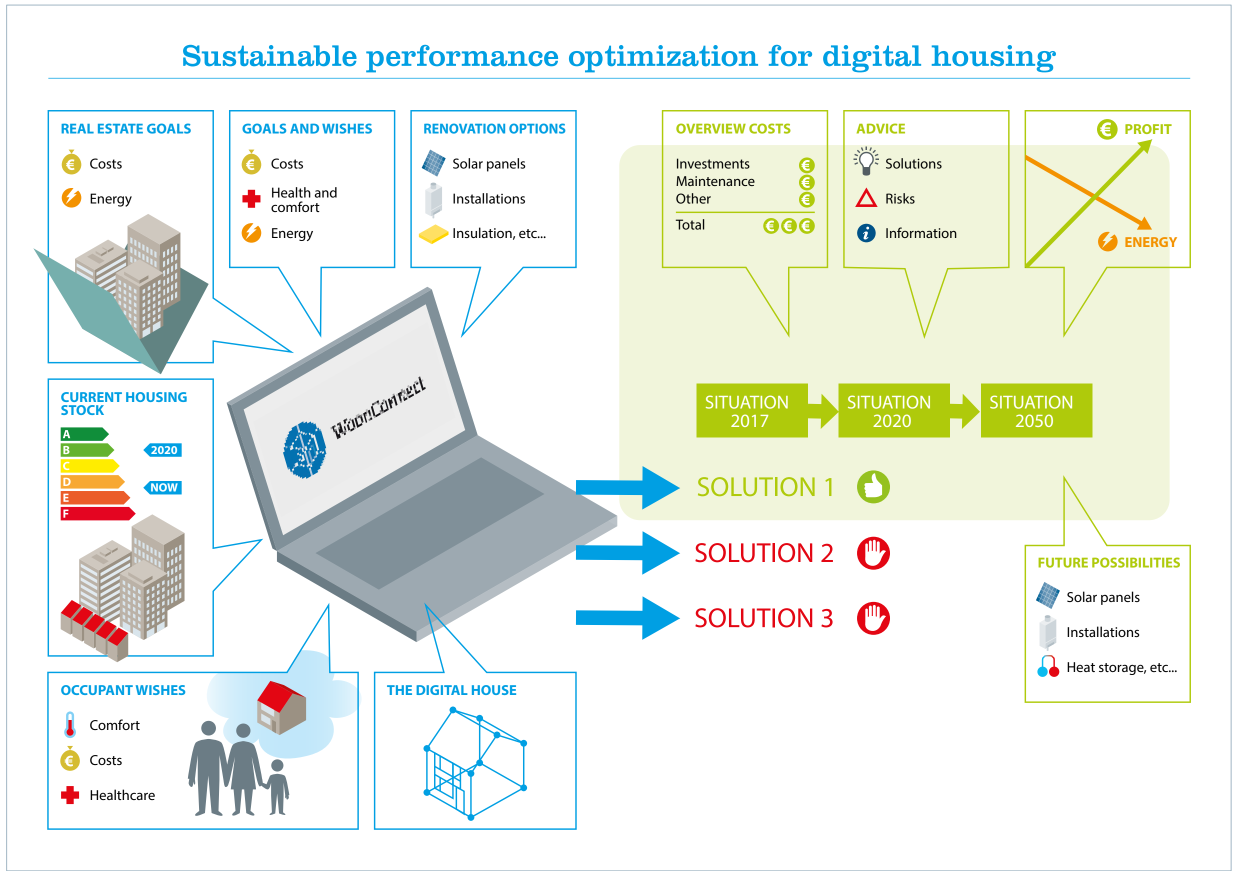
Immanuel Geesing MSc., Eindhoven University of Technology, PDEng 2016



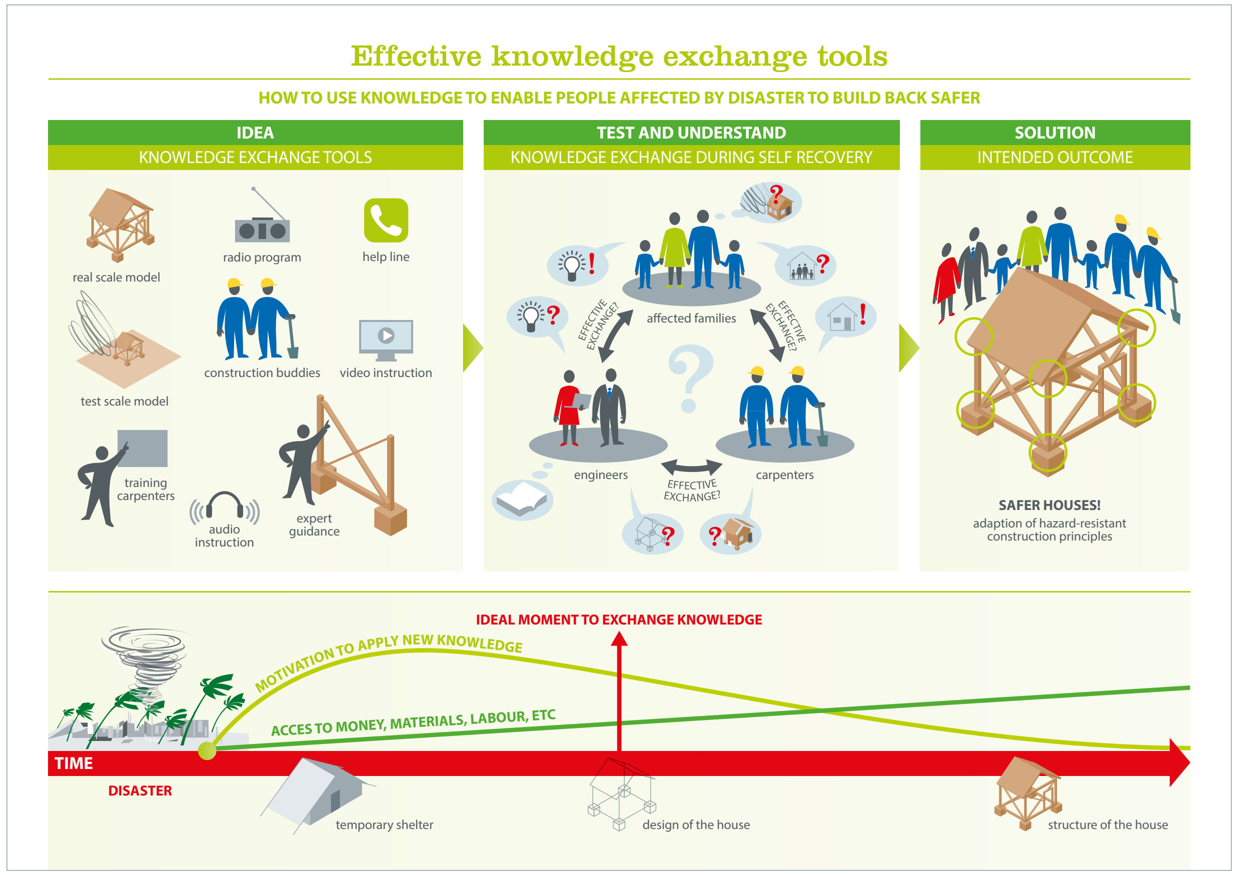
Tugce Tosun–Uslu MSc., Eindhoven University of Technology, PDEng 2015



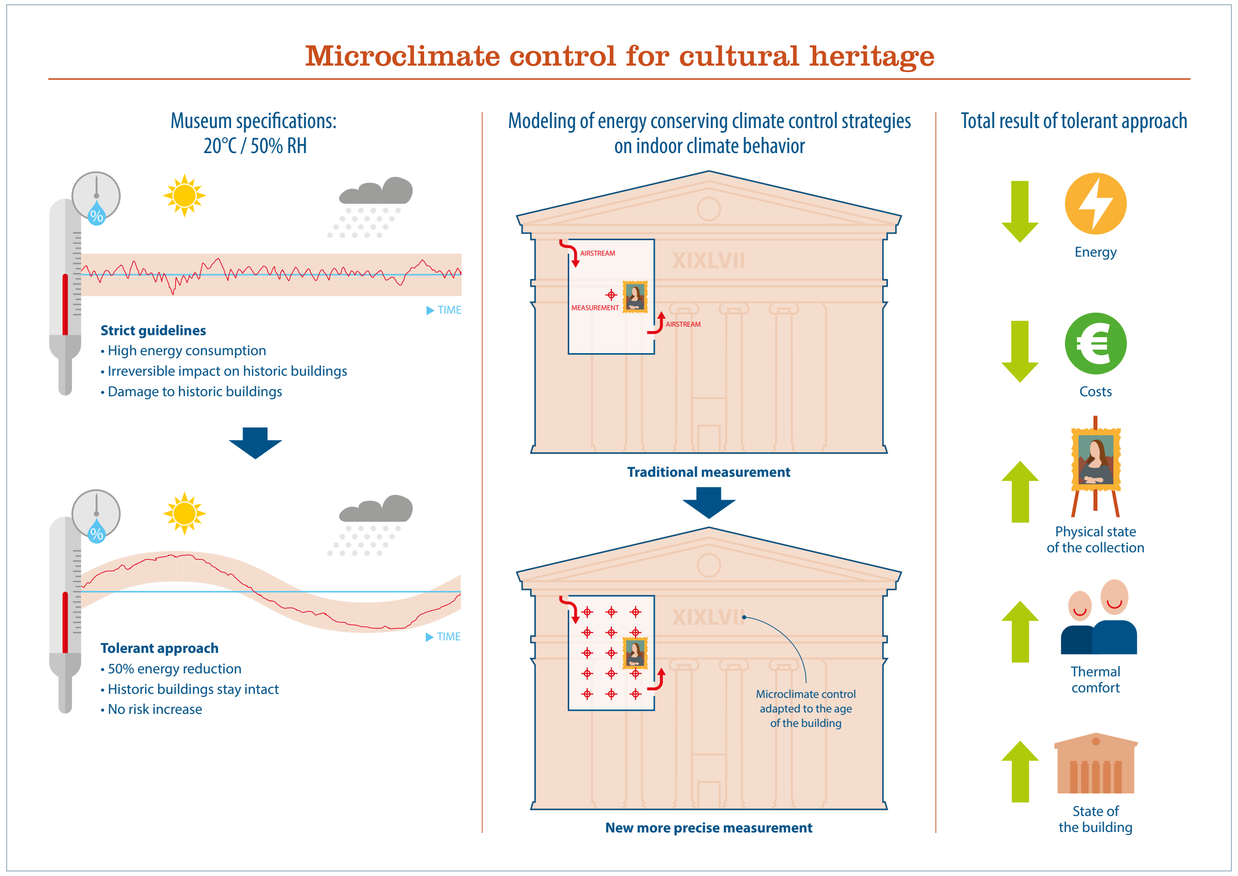
Evi Ploumpidou, Eindhoven University of Technology, PDEng 2016



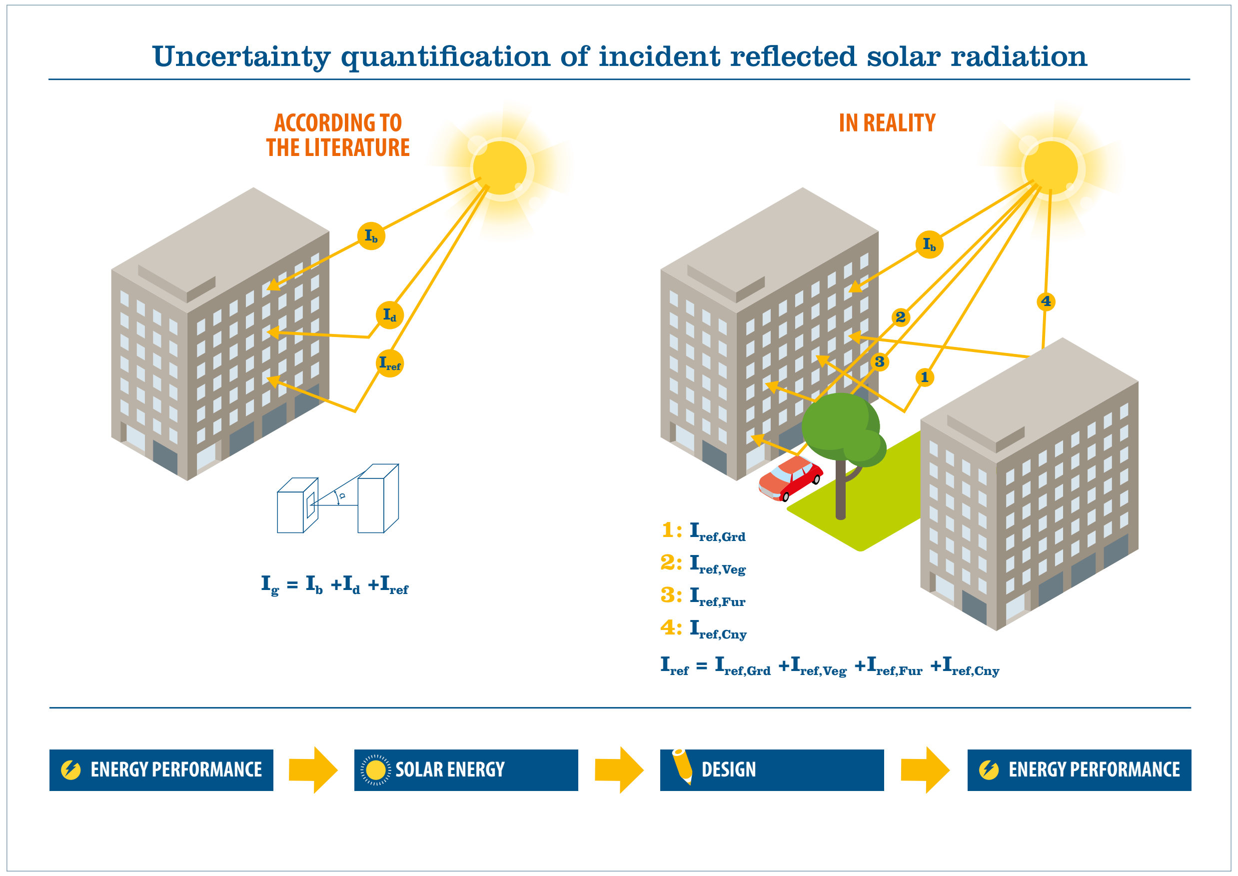
ir. Randy van Eck, Eindhoven University of Technology, PDEng Project 2017



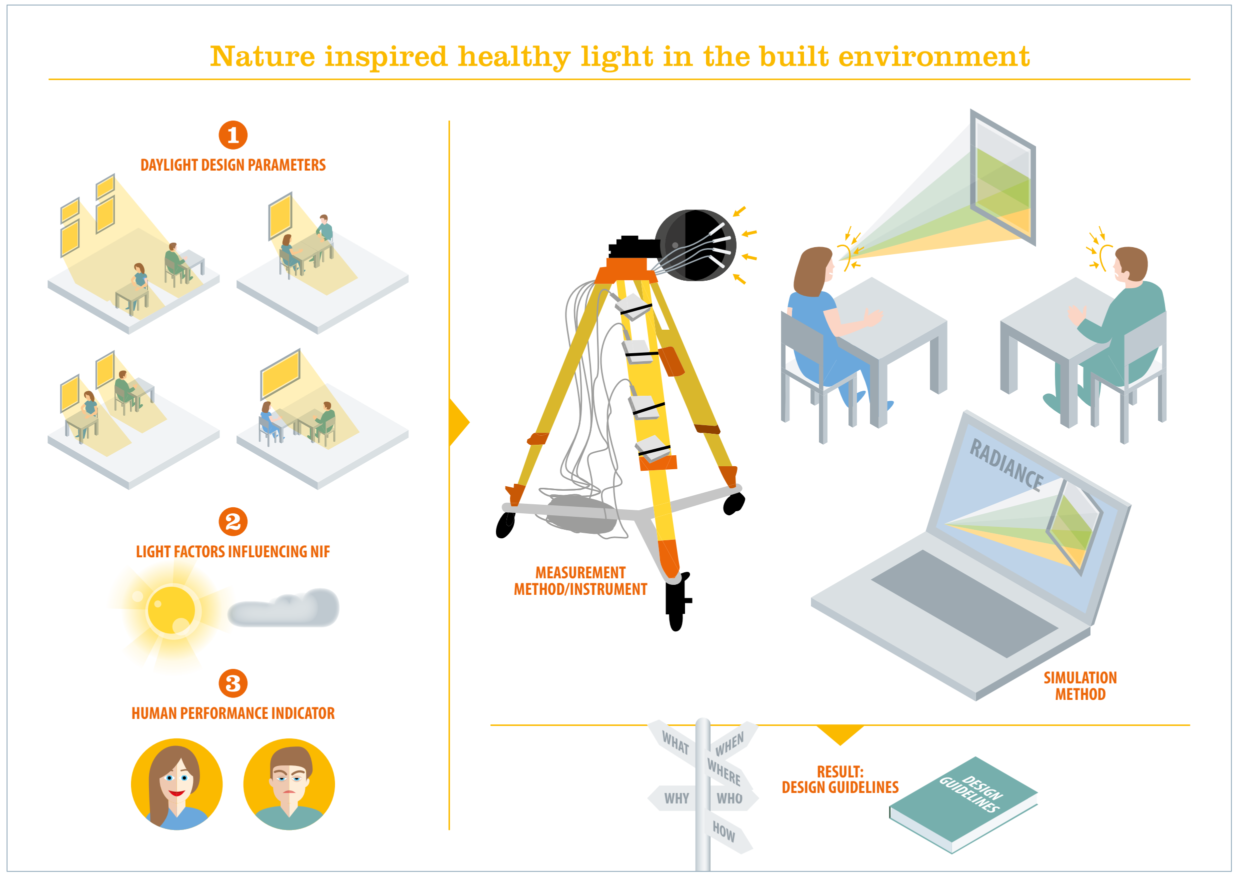
Eefje Hendriks, Eindhoven University of Technology, 2017



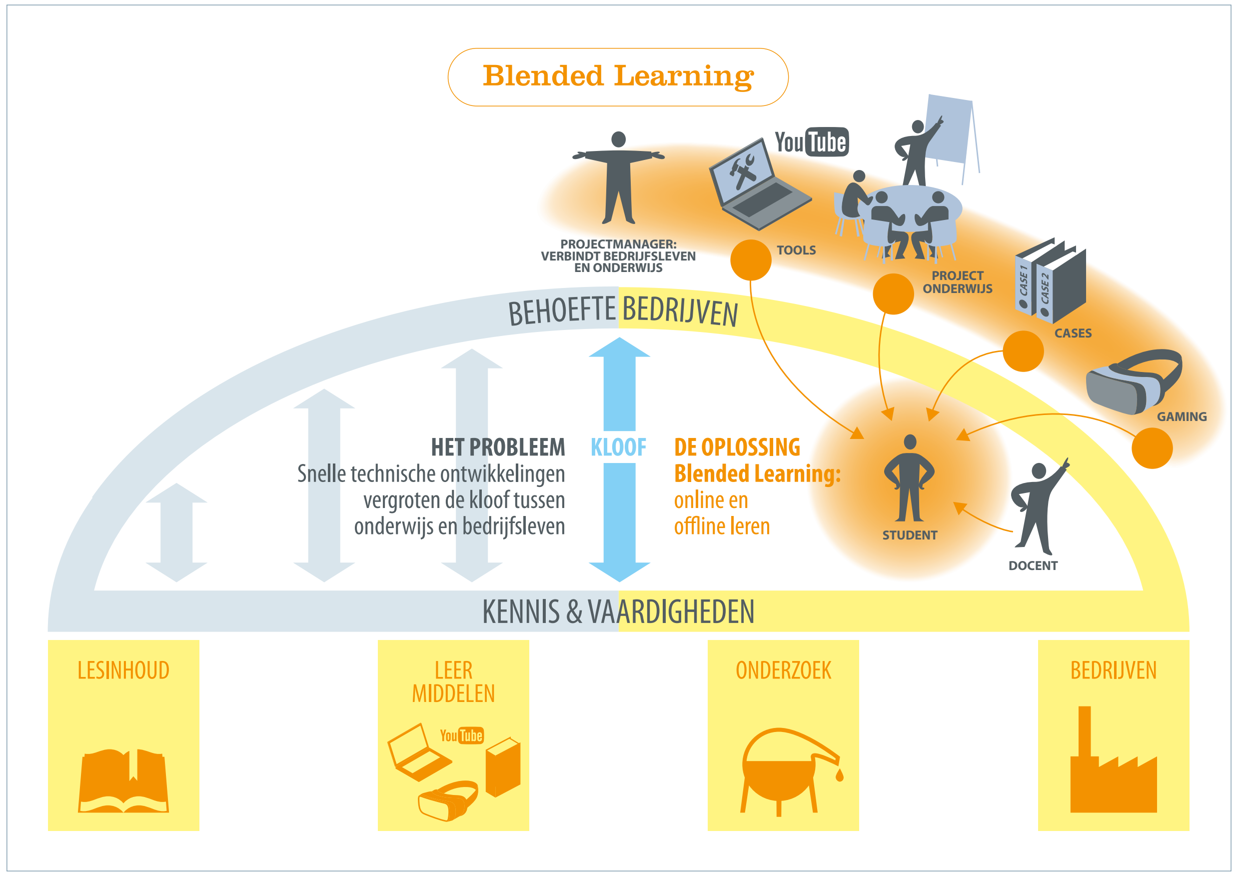
Karin Kompatscher, Eindhoven University of Technology, 2017



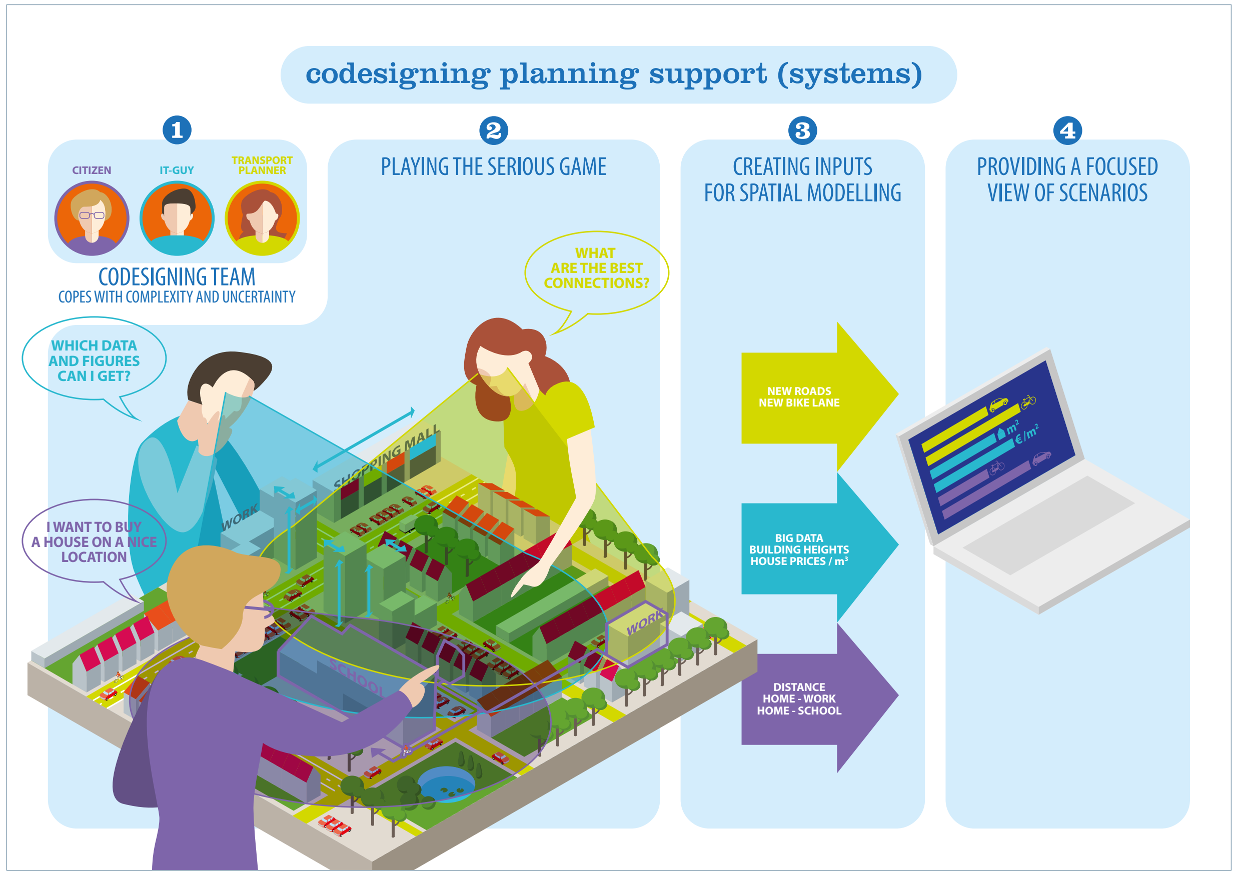
Maryam Meshkinkiya, Eindhoven University of Technology, 2017



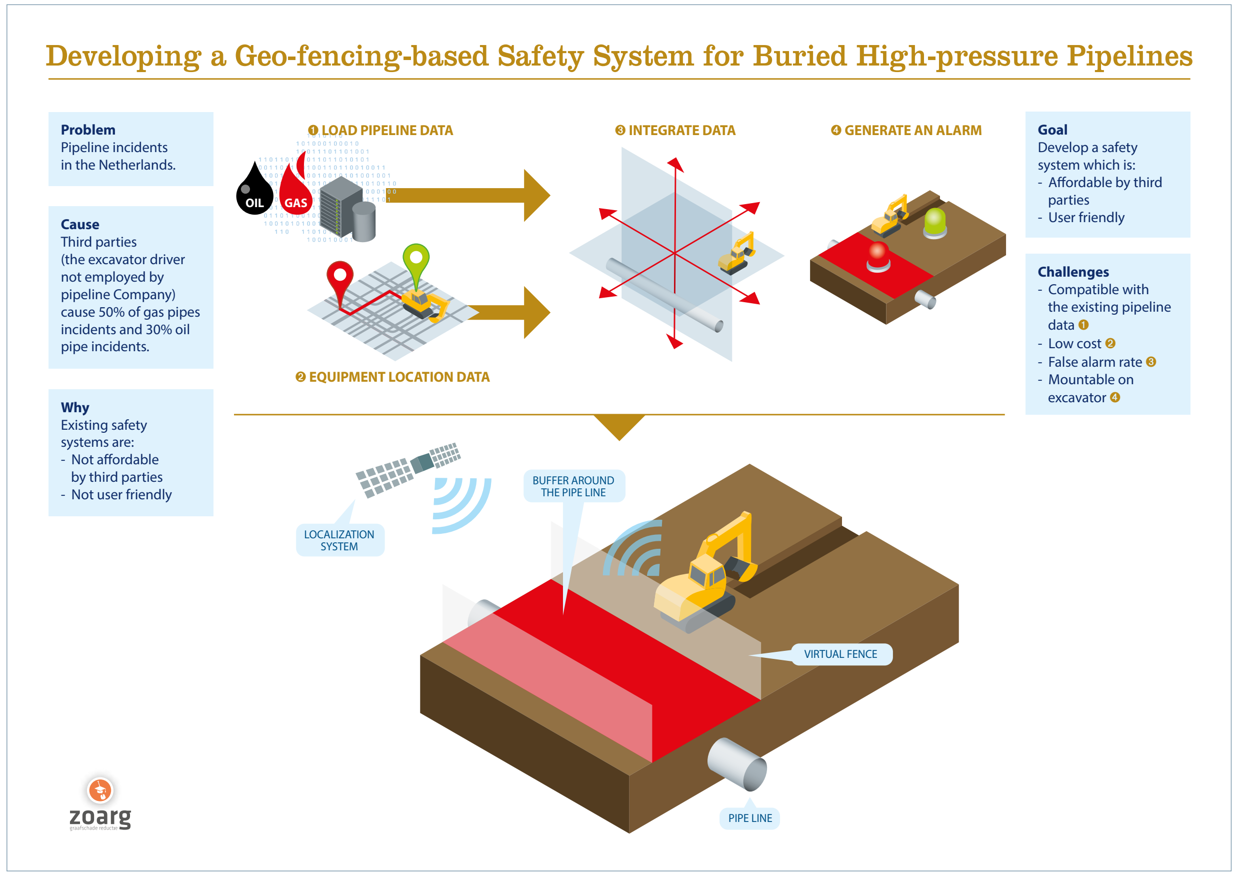
Parisa Khademagha, Eindhoven University of Technology, 2017



Janine Profijt, University of Twente, 2016

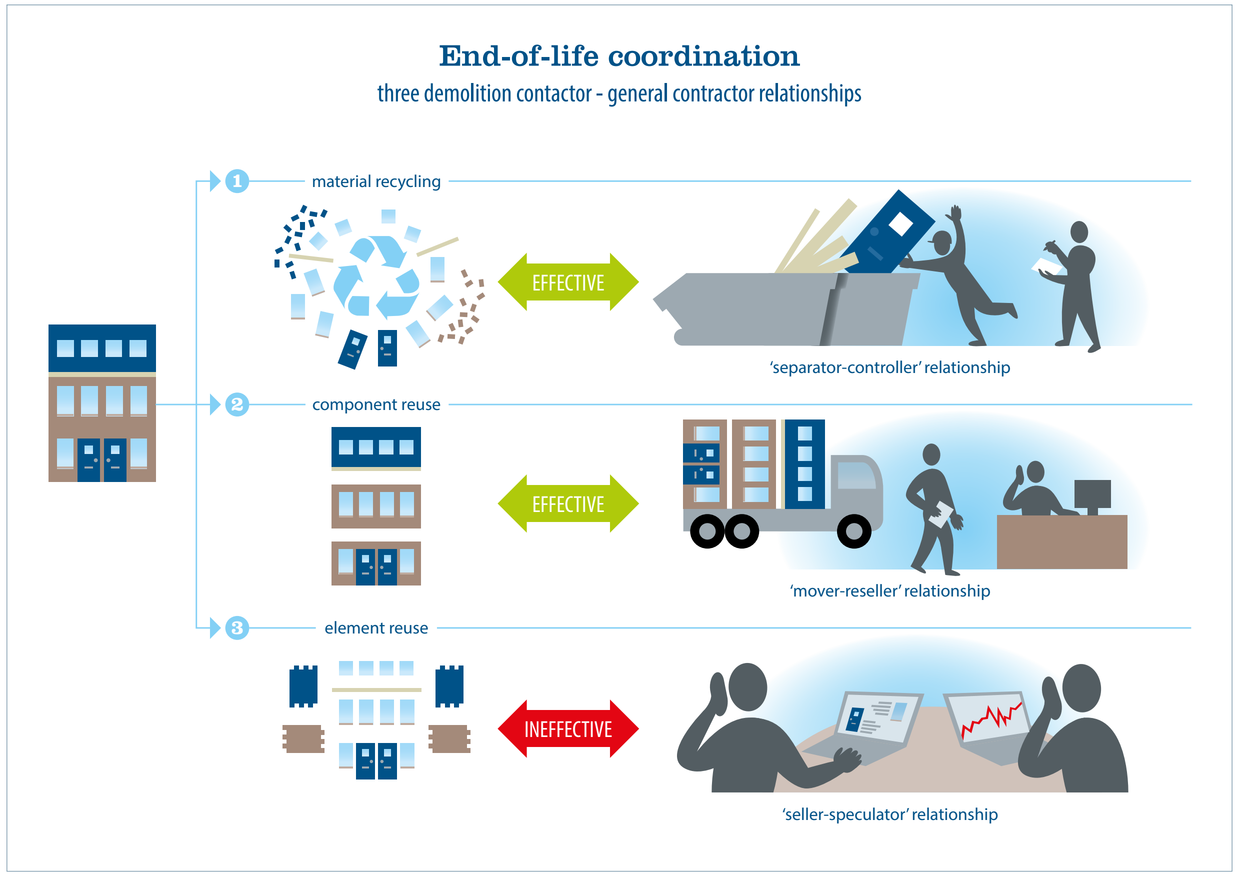


Carissa Champlin, University of Twente, 2016

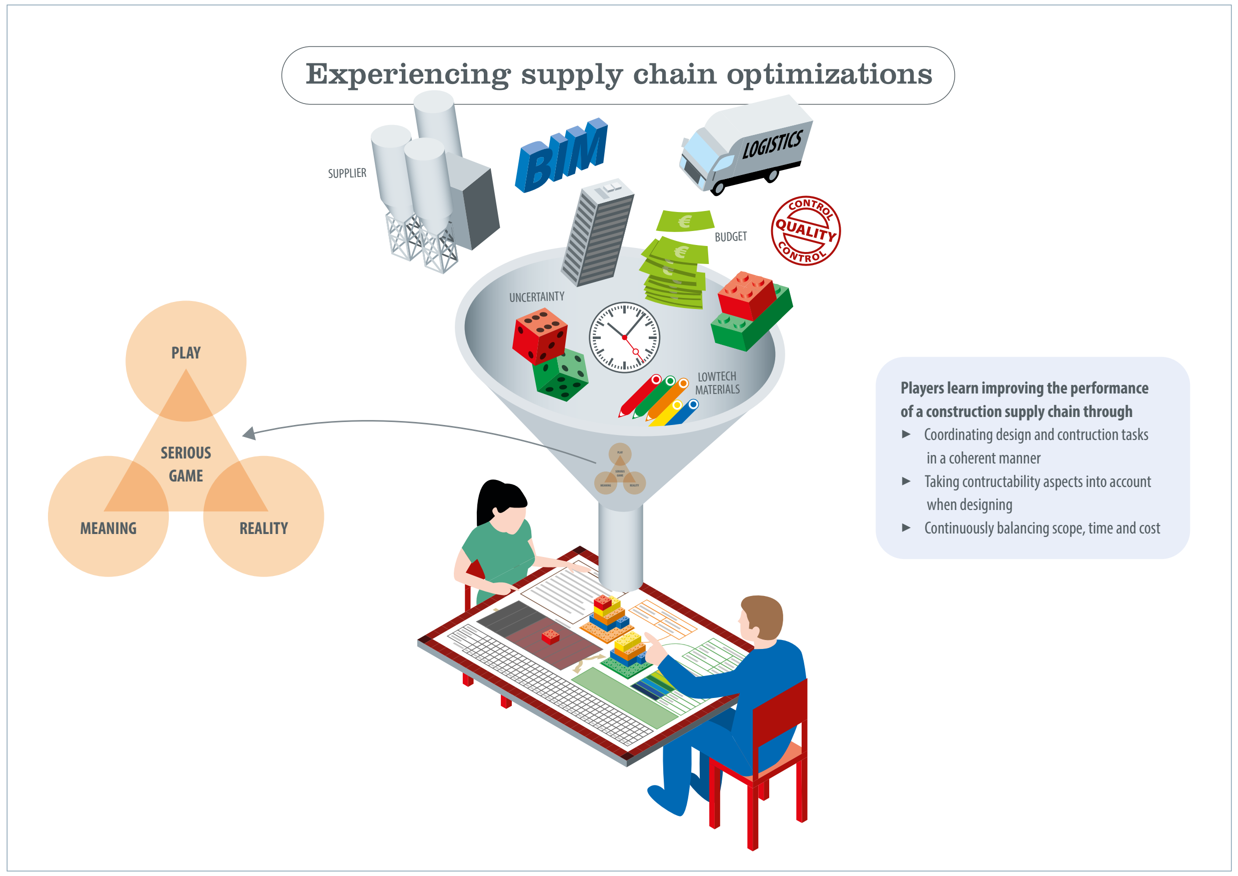


Saeid Asadollahi, University of Twente, 2017

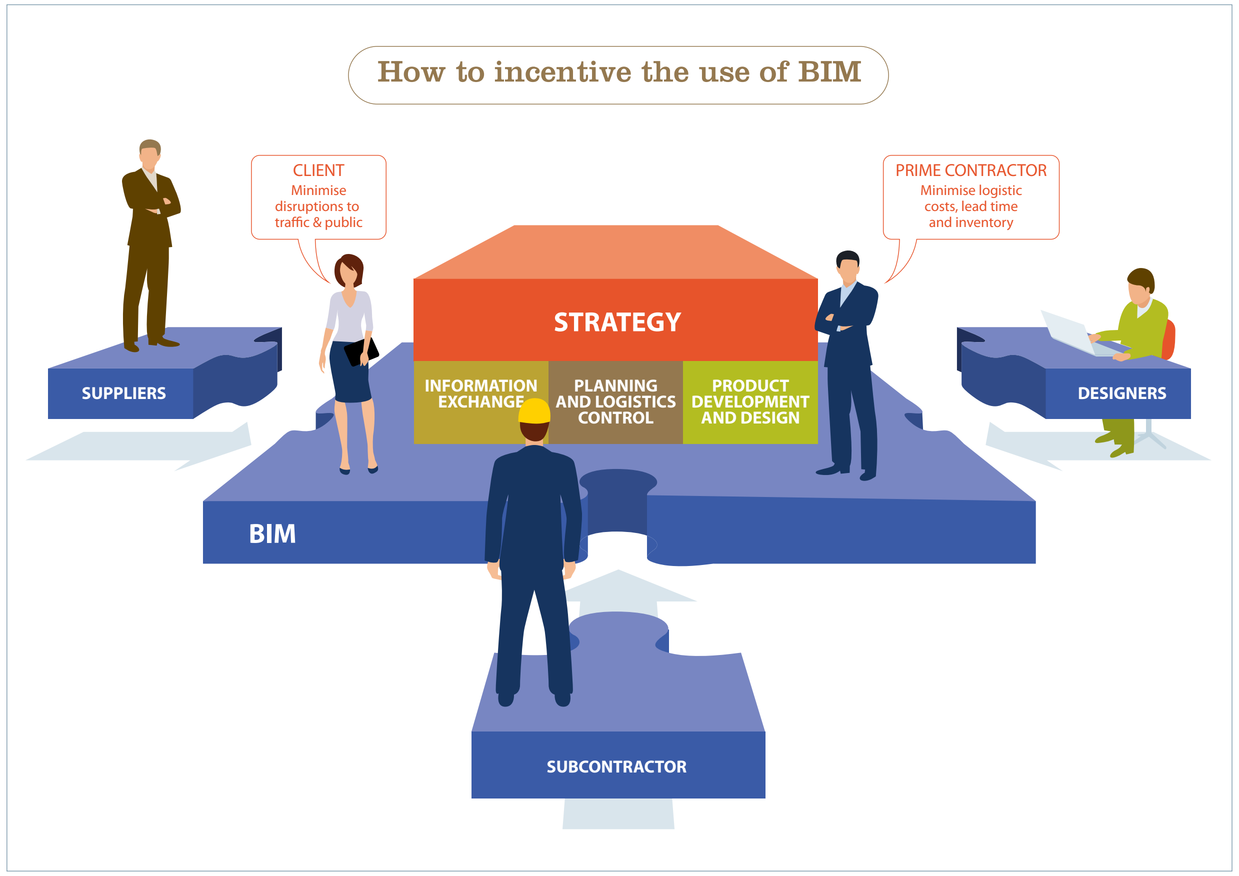
Priya Darshini Cheyyar Nageswaran, University of Twente, 2017



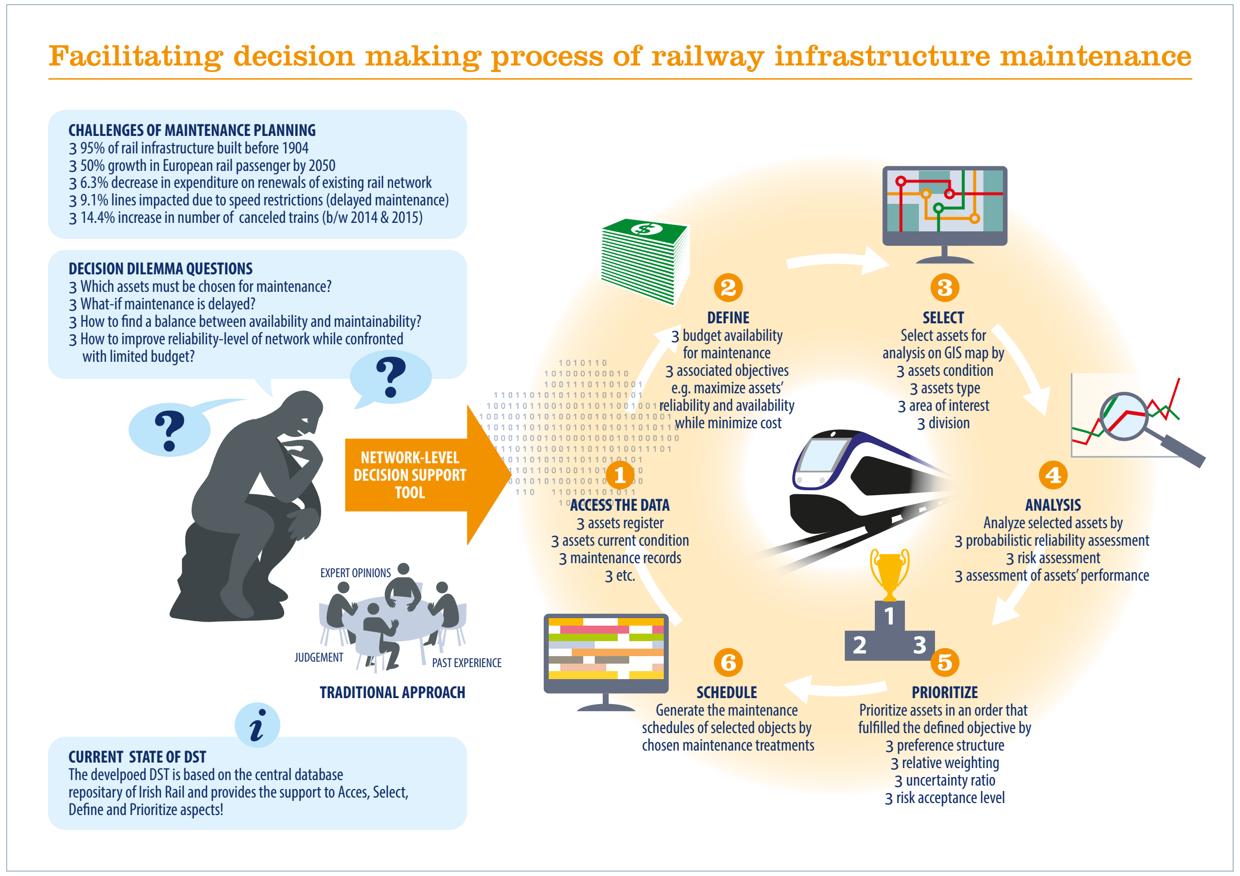
Marc van den Berg, University of Twente, 2017



Marc van den Berg, University of Twente, 2016

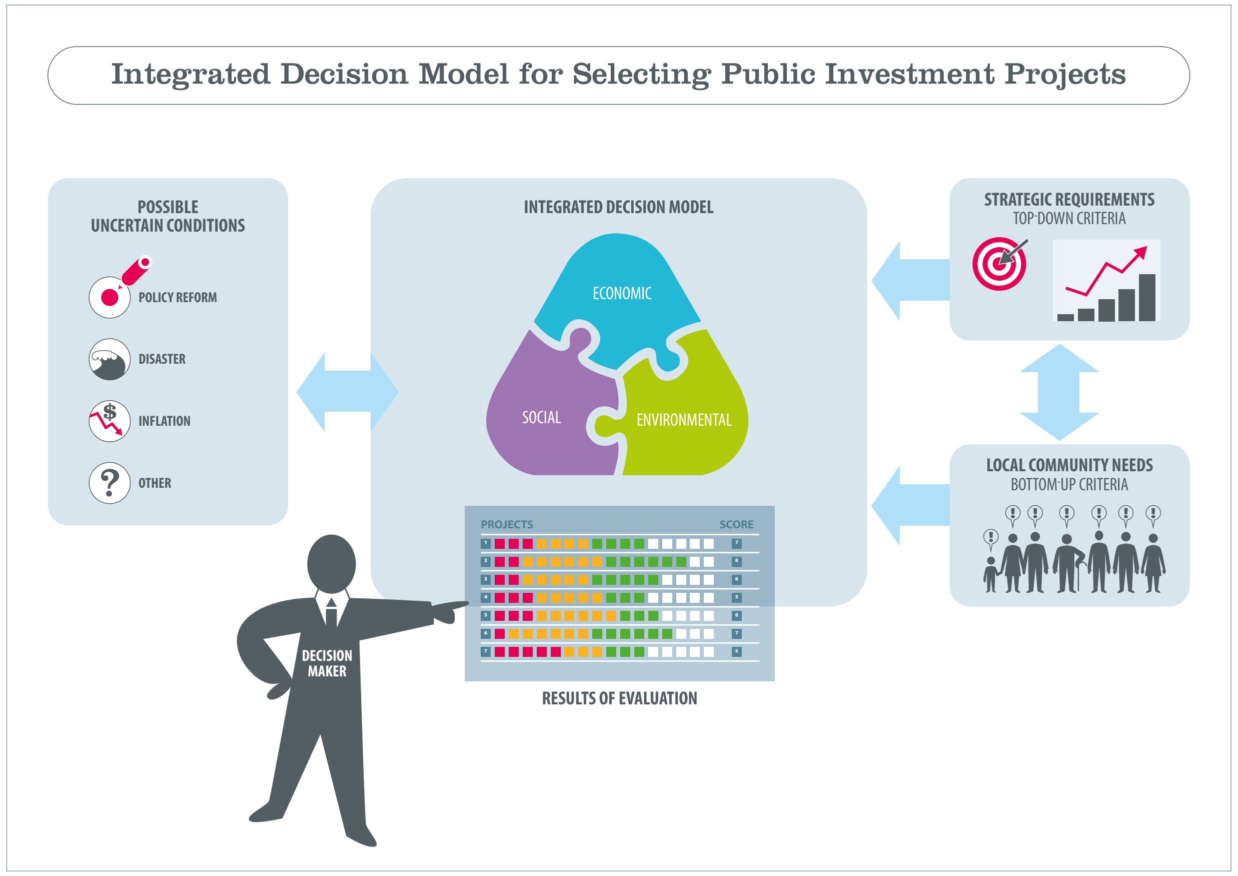


Ruth Sloot, University of Twente, 2016

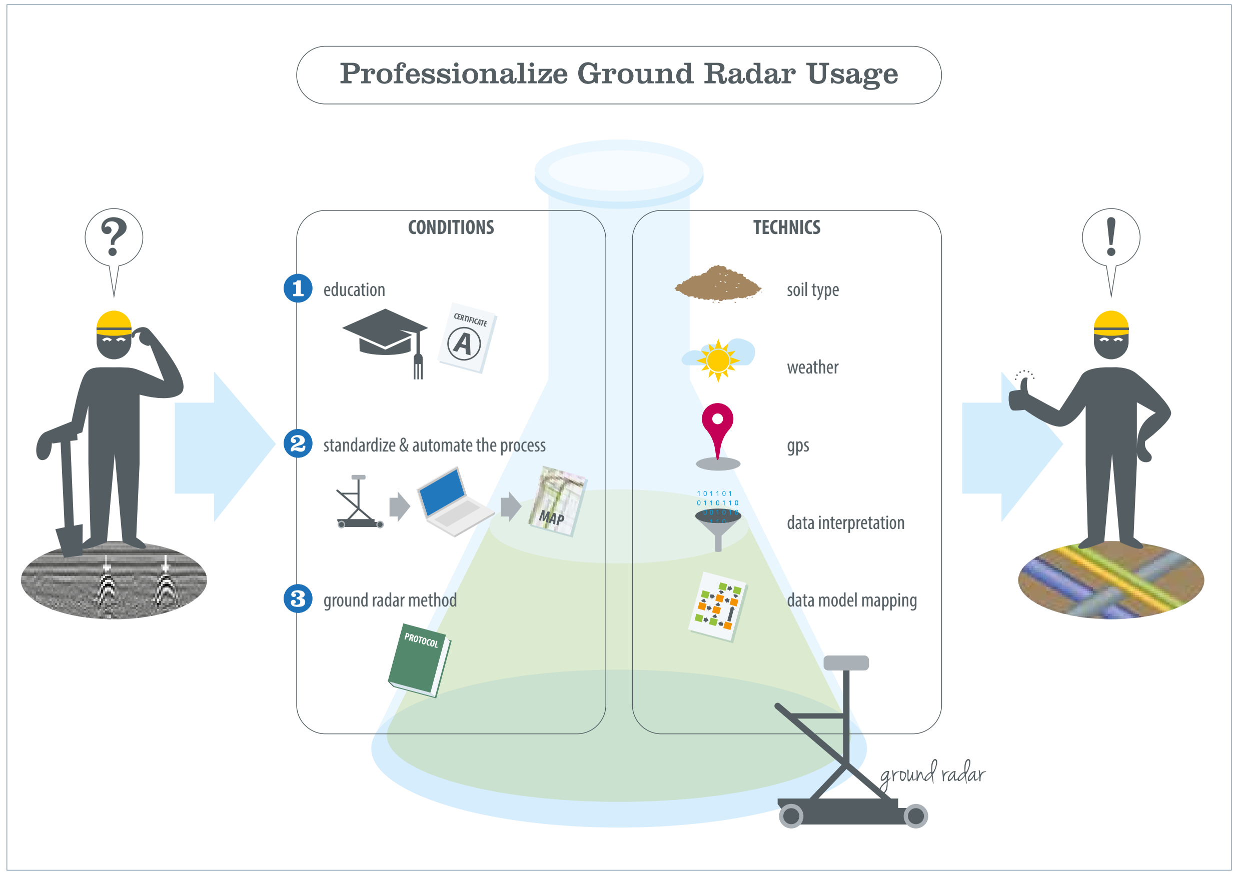


Zaharah Allah Bukhsh, University of Twente, 2017

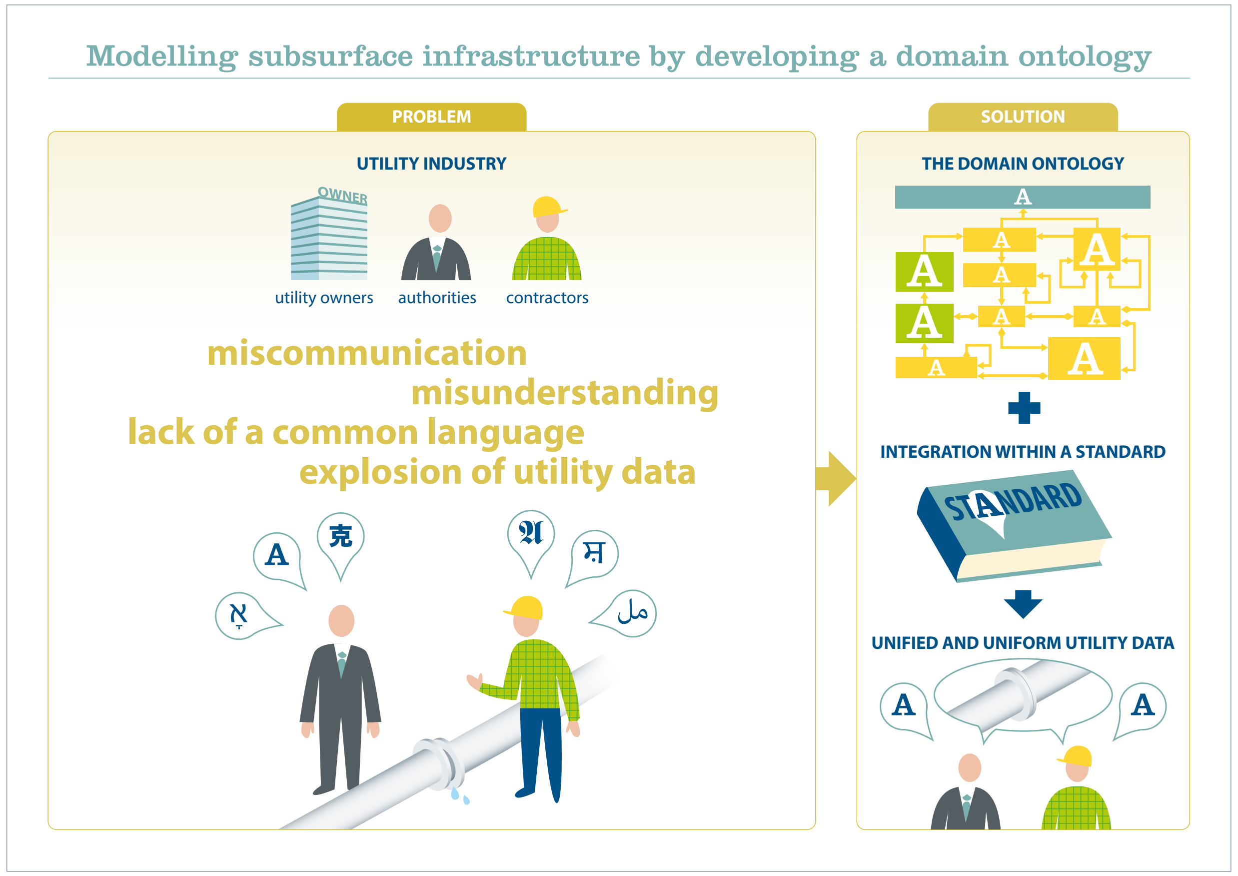
Paulina Racz, University of Twente, 2017



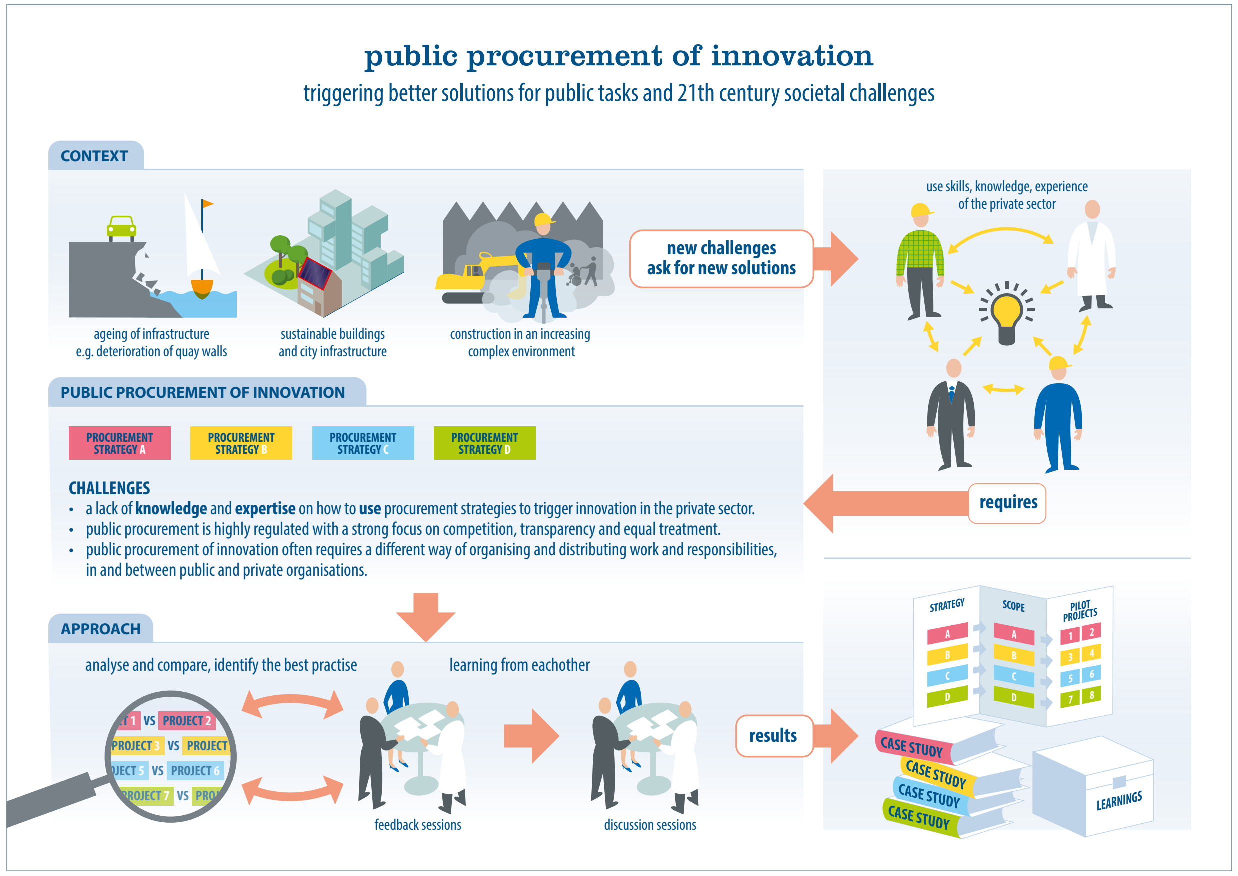
Pintip Vayarothai, University of Twente, 2016



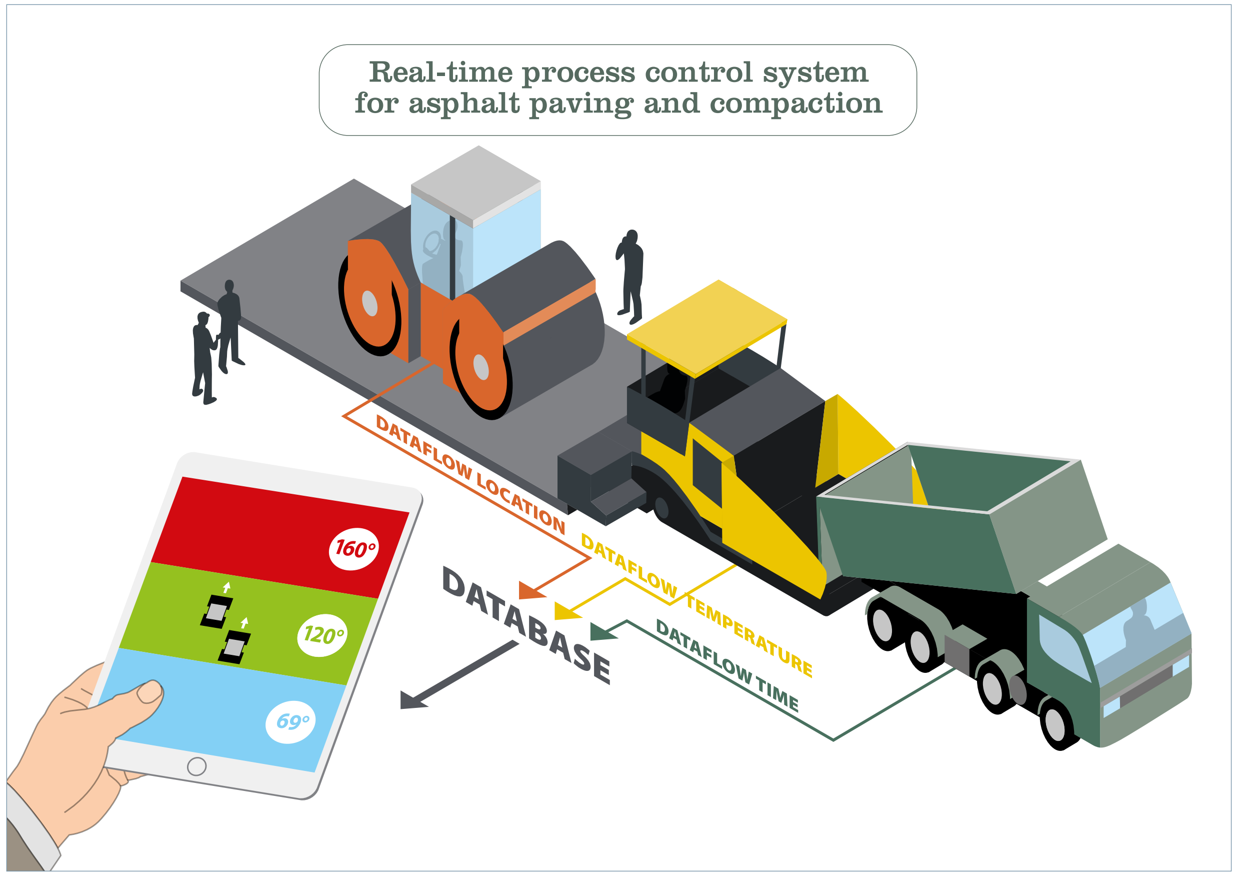
Léon olde Scholtenhuis, University of Twente, 2016



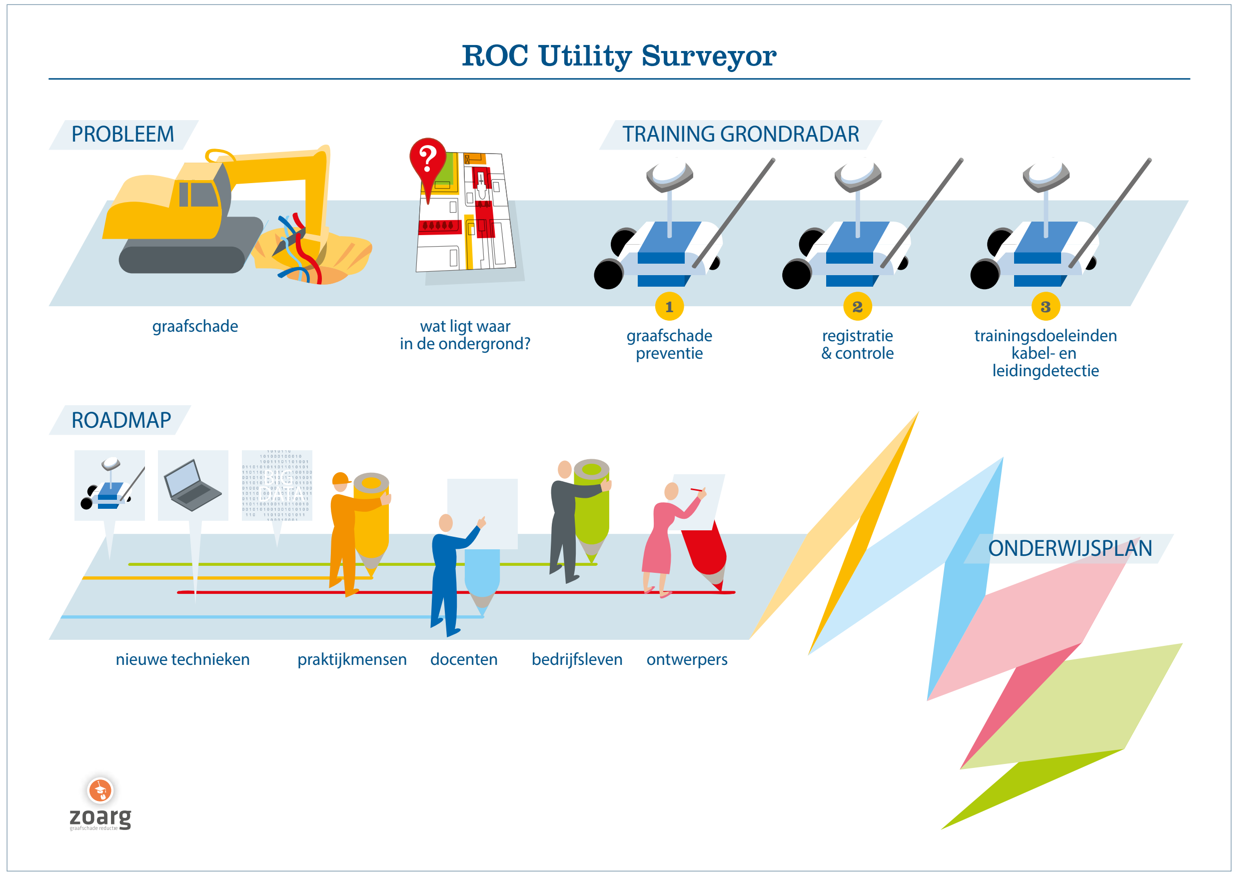
Ramon ter Huurne, University of Twente, 2017



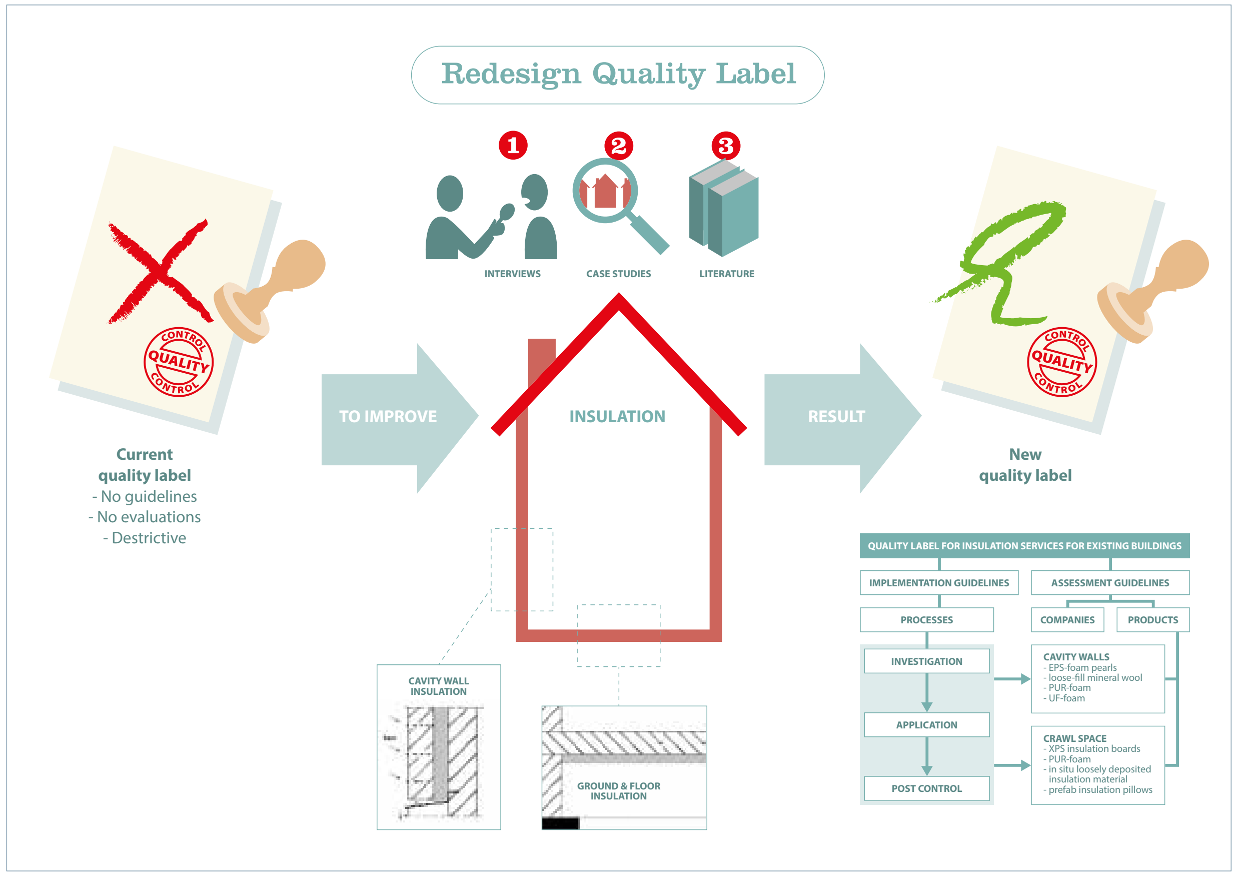
Bert Lenderink, University of Twente, 2017



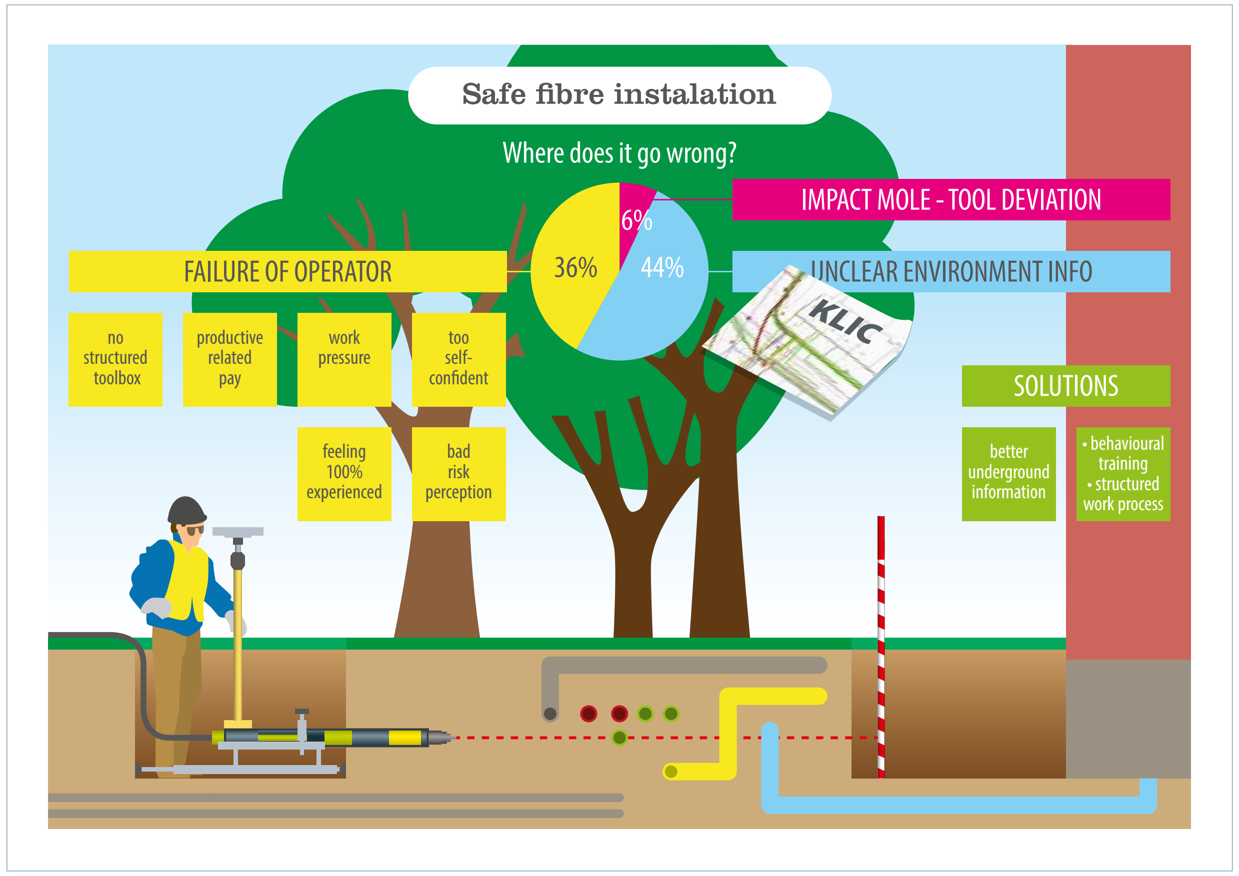
Denis Makarov, University of Twente, 2016



Dieuwertje ten Berg, University of Twente, 2017



Twan Rovers, University of Twente, 2016

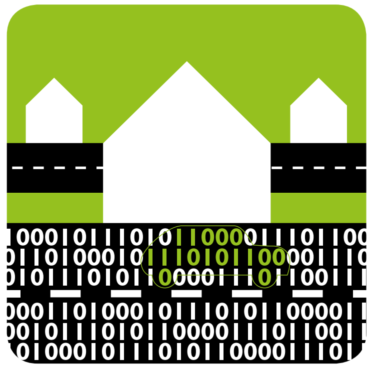


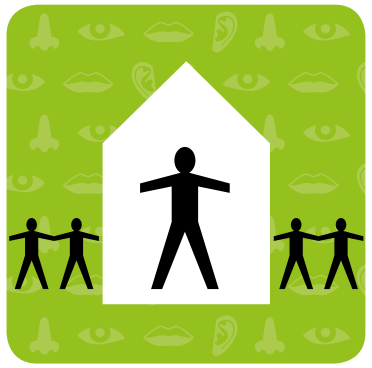
Fatemeh Mahmoudi, University of Twente, 2016

POLICY

De Toekomst wordt Gebouwd
Built Society Smart Reality
Smart Liveable Cities

4TU.Bouw, representing the combined research and educational programs of the affiliated faculties, took part in several initiatives to help shape future research needs in collaboration with industry branch organisations and academic colleagues. Especially the development of the National Science Agenda instigated by the Dutch government was a major reason to combine forces and develop specific research plans and strategies based on a thorough inventory of our own university's ambitions and societal demands.





DE TOEKOMST WORDT GEBOUWD

Nederland is het resultaat van een eeuwenlang bouwproces, Nederland is het resultaat van maatwerk gedurende vele eeuwen. Er is land gewonnen, er is land verdedigd tegen het water, er zijn steden en dorpen gebouwd, er is infrastructuur gebouwd: van wegen en dijken, van polders en luchthavens. Mensen beleven het land, de ruimte, het (binnen)klimaat van gebouwen, en hebben verbinding met anderen via fietspad, spoor, snelweg, digital highway, water uit de kraan, vuil naar het stort en waterzuivering, elektriciteit voor levensbehoeften en luxe, droge voeten, veilige havens - een greep uit vanzelfsprekendheden die mede mogelijk gemaakt zijn door de bouw en civiele techniek.

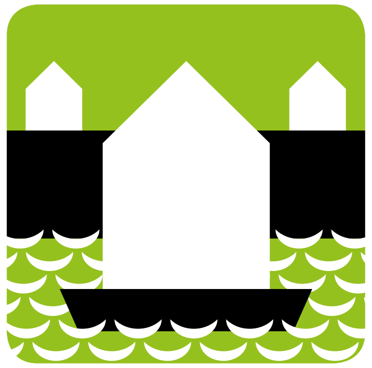
De ontwikkeling van de samenleving en de technologie vragen voortdurend aanpassing van de fysieke leefomgeving. Voorspellingen over de gevolgen van klimaatverandering zoals zeespiegelstijging, de noodzakelijke transitie naar decentrale, duurzame energieproductie en de noodzaak tot een gesloten kringloop voor grondstoffen, maakt een versnelde ontwikkeling en toepassing van innovaties in de gebouwde omgeving van groot belang, voor de huidige generaties, en alle die volgen.

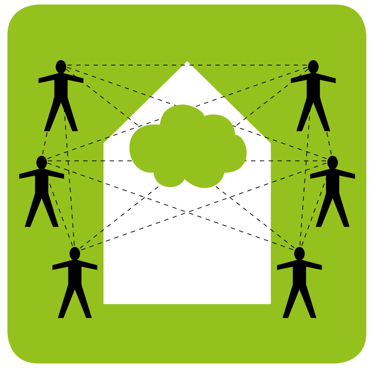
Desondanks kampt de bouw met het imago conservatief en versnipperd te zijn. Echter, de constructieve zekerheid van producten van de bouwsector zijn formidabel (voor infrastructurele objecten als waterkeringen is 100 jaar een absoluut minimum), de ontwikkelingen in de afgelopen decennia ten aanzien van energiecomfort en – zuinigheid, nieuwe, slimme bouwmaterialen zijn spectaculair te noemen. De bouwsector is bij uitstek de omgeving waarin de innovaties uit talrijke vakgebieden in geïntegreerde vorm hun uiteindelijke toepassing vinden. Zo heeft bijvoorbeeld geen enkele innovatie zoveel kwaliteitsjaren aan het leven van de mens toegevoegd als adequate sanitatie in zijn leefomgeving. Publieke sanitatie is een goed voorbeeld van een historisch, en 'ongoing', project dat alleen tot stand kon komen door effectieve werking van de gouden driehoek tussen normstellende en faciliterende overheden, voortschrijdende inzichten vanuit onderwijs en wetenschappen, en voortvarende uitvoering door de private sector.

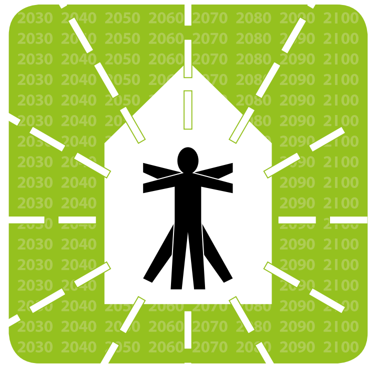
Daarom heeft het samenwerkingsverband van bouw-faculteiten van de drie Technische Universiteiten in Nederland, 3TU.Bouw, in nauwe afstemming met de bouwsector en de hele bouw gerelateerde onderwijsketen, een 8-tal thema's geagendeerd die richtinggevend zullen zijn voor toekomstig wetenschappelijk en onderzoek. Op basis van deze thema's zijn vragen geformuleerd voor de Nationale Wetenschapsagenda, welke in de volgende pagina's gepresenteerd worden.

De toekomst wordt gebouwd!

Samenstelling op basis van bijdragen medewerkers Technische Universiteit Delft - Architecture & Civil Engineering and Geosciences, Technische Universiteit Eindhoven - Built Environment en Universiteit Twente - Engineering Technology; ondersteund door Bouwend Nederland.







Redactie
Alexander Schmets met Siebe Bakker, Ulrich Knaack & Lisa Kuijpers

Graphic Design – Icons
Dré Kampfraath & Frans Schupp

PERCEPTIE & ACCEPTATIE: DE MENSELIJKE MAAT

Bouwen gaat in de eerste plaats over mensen van alle leeftijden, met verschillende culturele achtergronden en sterk uiteenlopende behoeften. Ze hebben behoefte aan beschutting, ontmoeting en samenzijn, maar ook aan vrijheid, herkenning, concentratie en rust; dit alles in een veilige en gezonde leefomgeving. Tegelijkertijd wordt hun leefomgeving steeds complexer. De wereld digitaliseert, de mens individualiseert en wordt ouder dan voorheen. Er worden hogere eisen aan burgerschap en persoonlijk initiatief gesteld. Daarnaast worden stedelijke gemeenschappen pluriformer en is opleiding een voorwaarde om mee te doen.

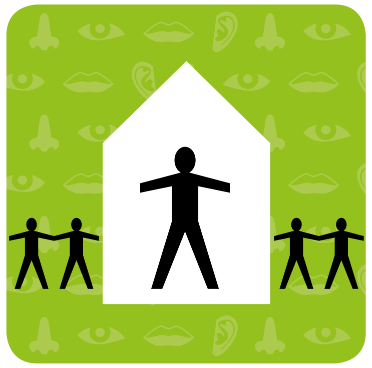
Hoe kunnen ingrepen in de gebouwde omgeving bijdragen aan het leven van de mens als individu en als onderdeel van een gemeenschap?

Alle ontwikkelingen in Nederland vinden plaats in een volledig door de mens gecreëerde omgeving die identiteit en herkenning verschaft, of juist gevoelens van onbehagen en achterstand doet ontstaan. Nederland blijkt een redelijk gelukkig land te zijn, maar toch wordt er steeds meer hinder ervaren van medeburgers, van bouwactiviteiten en van verkeer; fijnstof, stank, lichtvervuiling en geluidshinder. Hinderbeperking en flexibel bouwen worden belangrijker.

Door maatschappelijke trends zoals vergrijzing en veranderingen met betrekking tot wonen, zorg, pensioenen en multi-culturaliteit neemt de aandacht voor de wensen en behoeften van eindgebruikers en de vraag naar comfort, gemak en maatwerk toe.

De focus op techniek verandert naar een focus op de mens: de techniek socialiseert. De gebouwde omgeving moet niet alleen praktische en esthetische, maar ook ecologische en sociaal-maatschappelijk doelen dienen. Gebruikers moeten meer betrokken worden in processen in de bouw, co-creatie, om daarmee tegelijkertijd legitimiteit en acceptatie te borgen.

Daarnaast is het zaak dat de eindgebruiker professionaliseert, eventueel met digitale ondersteuning, om optimaal gebruik ten aanzien van de levenscyclus te bereiken. Er ontstaan nieuwe vraagstukken wat betreft privacy, de gebruiker mede-verantwoordelijk maken voor de openbare ruimte en het optimaliseren van de voordelen van dicht op elkaar wonen. Onderzoek is nodig naar passende ruimtelijke oplossingen en nieuwe voorzieningen, met een focus op de mens.



Science for Science
Hoe gaan we om met de bestaande voorraad aan gebouwen die leeg staan of onderbenut zijn?
Hoe verhoudt de mens als individu zich tot een geautomatiseerde samenleving, en wat betekent de voortgaande sensor-dichtheid voor zijn privacy?
Hoe ziet het energie-landschap eruit bij decentrale productie na de energie transitie?
Hoe kunnen waarden, zoals comfort en esthetische kwaliteit, gedefinieerd, gemeten en beoordeeld worden als input voor sturing?

Science for Society
Hoe kunnen we gebouwgebruikers professionaliseren en stimuleren, opdat zij het gebouw zo energiezuinig mogelijk gebruiken, zonder dat hun gezondheid in het gedrang komt?
Hoe kunnen gebouwen ontworpen worden die gezond zijn (optimaal binnenmilieu) of zelfs mensen kunnen genezen?
Hoe kan de mens gestimuleerd worden zich (mede)eigenaar te gaan voelen van de collectieve goederen in de bebouwde omgeving?
Hoe kan door middel van architectuur en interactief ontwerpen de mens zo veel mogelijk gestimuleerd en ondersteund worden in zijn dagelijkse bezigheden?

Science for Competitiveness
Welke financiële arrangementen zijn nodig om meerdere functionaliteiten in de gebouwde omgeving te integreren?
Hoe ziet de economie van het flexibel gebruiken van gebouwen op de lange termijn er uit?
Hoe kan hindervrij geconstrueerd worden tegen dezelfde kosten en kwaliteit?
Hoe zorgen we dat energie en de ‘bio-based economy’ niet ten koste gaan van voedselproductie?
Hoe zorgen we ervoor dat arme landen meeprofiteren van hun eigen grondstoffen?

Science for Science
Hoe kan alle door sensors vergaarde data gefilterd en positief gebruikt worden?
Welke vereisten stelt de energietransitie aan de stedelijke omgeving?
Hoe kunnen onze steden klimaatneutraal en klimaat-robuust gemaakt worden?
Wat is erfgoed en hoe kan bepaald worden wat de toekomstige waarde ervan is en welk type gebruik erbij past? Hoe kan techniek ingezet worden om het erfgoed te bewaren?
Kan door middel van toepassing van meer groen in de stad, eventueel aangevuld met andere technieken, de stedelijke omgeving CO2 neutraal gemaakt worden?

Science for Society
Hoe kan door middel van het ‘smart city’ concept de leefbaarheid in steden geoptimaliseerd worden?
Hoe kan een balans gevonden worden tussen privacy belangen en verregaande data vergaring?
Hoe kan door beleid op het gebied van ruimtelijke ordening steden beter bereikbaar worden?
Hoe kan toepassing van ontwerp en technologie leiden tot behoud en verbetering van een duurzame en open publieke ruimte?

Science for Competitiveness
Hoe kunnen de best practices opgedaan in Nederlandse steden verpakken en vermarkten aan het buitenland?
Hoe kunnen we reeds toegepaste smart technologieën mee laten evolueren in de tijd?
Wie is eigenaar van door sensors vergaarde informatie? Hoe kan enkel relevante data naar organisaties gecommuniceerd worden?
Op welke wijze kan het zelf-producerend vermogen van stedelijke omgevingen worden gemaximaliseerd?
Hoe optimaliseer je op een respectvolle manier de opbrengsten van erfgoed?

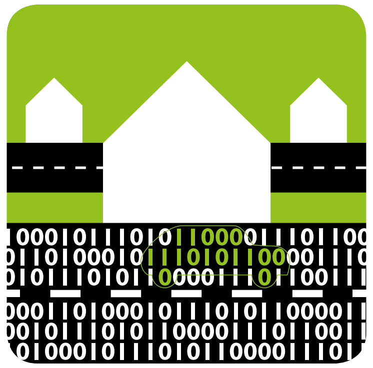
LEEFBAAR & EFFICIËNT: SMART CITIES

Over de hele wereld en ook in Nederland trekken steeds meer mensen vanuit landelijk gebieden naar de stad, er ontstaan nieuwe metropolen en mega cities. Daarnaast hebben demografische trends, zoals vergrijzing en kleinere huishoudens, een grote invloed op de gebouwde omgeving en haar samenstelling. Om steden leefbaar en toekomstbestendig te houden is een transitie van de stad noodzakelijk. Maar, de stad is een complex systeem dat niet met louter korte termijn maatregelen te veranderen is. Hoe ziet de stad van 2050 er uit en hoe kunnen wij hier naartoe werken?

De stad is een samenspel van sociale, economische en ecologische factoren, die met elkaar in balans dienen te zijn. Problemen die momenteel urgent worden voor steden zijn een ongezond stedelijk klimaat, onveiligheid, wateroverlast en overlast door verkeer. In steden is ruimte nodig voor verduurzaming en vergroening, maar ruimte is schaars in Nederland. Anderzijds komen er steeds meer kantoor- en fabrieksgebouwen leeg te staan. Welke nieuwe technologieën zijn beschikbaar om hier een oplossing aan te bieden? Het smart city concept biedt hier vele mogelijkheden.

Smart cities zijn gebaseerd op nieuwe technologieën, zoals elektrisch vervoer, straatverlichting met sensoren en mobiele netwerken. Er is echter nog veel onderzoek nodig naar de toepassingsmogelijkheden van deze nieuwe technologieën in de gebouwde omgeving. Dit onderzoek vraagt een samenwerking tussen stadsbewoners, stadsbestuur, onderzoeksinstituten en de bedrijfsleven. Daarnaast dient nieuwe kennis ontwikkeld te worden met betrekking tot stedenbouw en bestuurlijke instrumenten om zowel voor de lokale als globale schaal tot nieuwe oplossingen te komen.

Het is belangrijk dat zoveel mogelijk belanghebbende partijen betrokken hierbij worden en dat de resultaten van het onderzoek zichtbaar en tastbaar worden gemaakt. Zonder gericht onderzoek loopt Nederland als één van de dichtstbevolkte landen ter wereld het risico om aan leefbaarheid in te boeten, zolang problemen als toenemende verdichting, onveiligheid en een ongezond leefmilieu niet aangepakt worden.



INFRASTRUCTUUR & VERVOER: SMART MOBILITY

De logistiek van grondstoffen, producten en personen is het belangrijkste fundament onder de economische ontwikkeling van een samen-leving: Nederland heeft zijn huidige welvaart er grotendeels aan te danken. Kenmerkend voor mobiliteit en logistiek zijn twee verschillende aspecten: enerzijds de modaliteit, zoals auto, trein, schip, vliegtuig of pijp- of kabelleidingen, en anderzijds de onderliggende infrastructuur, zoals wegen, bruggen en tunnels, spoor, water-wegen en havens en luchthavens. Modaliteit en infrastructuur dragen heel verschillende kenmerken, qua investering, levens-duur en innovatiesnelheid. In het afstemmen van ontwikkelingen en beperkingen van beiden schuilt een grote maatschappelijke opgave.

Infrastructuur aanleggen vergt veel planning, grote investeringen en anticiperen op ontwikkelingen voor lange tijdsperiodes, soms langer dan 100 jaar. De structurele eigenschappen van deze infrastructuur zullen door gebruik en externe omstandigheden verouderen, terwijl veilig gebruik gewaarborgd moet worden. Hierdoor is er behoefte aan nieuwe monitoringstechnieken die op elk moment de gezondheidstoestand van een object kunnen weergeven en onderhoud- en vervangingscycli kunnen aansturen. Door de dichtheid van de netwerken zal aanleg, onderhoud en vervanging steeds complexer en duurder worden, terwijl de acceptabele last en barrièrewerking voor de omgeving geringer zal moeten worden.

Dit vraagt om nieuwe processen, contractvormen, tot multifunctioneel ontwerp en nieuwe in-place recycling en upgrading strategieën. Daarnaast veranderen de kenmerken en infrastructurele behoefen van vervoersmodaliteiten snel, terwijl de eisen met betrekking tot veiligheid, geluidshinder en uitstoot vervuiling steeds strenger worden. De interface tussen de modaliteiten en hun infrastructuren wordt ook belangrijker: de uitdaging om goed functionerende multimodale knoop-punten te verwezenlijken. Verder zal de rol van de bestuurder door voortgaande ontwikkelingen op het gebied van sensoring en ICT steeds kleiner worden. Vervoersmiddelen digitaliseren snel, en zullen gaan interacteren met de omgeving.

Duurzame bereikbaarheid in snel verdichtende en qua vervoer dichtslibbende urbane regio's blijft een constante uitdaging. Hierin kunnen nieuwe geavanceerde verkeerssystemen een rol spelen om een optimale reistijd te laten samengaan met maximale veiligheid en geringste hinder. Tenslotte is het noodzaak te streven naar 100% emissieloos transport

Science for Science
Welke nieuwe vervoersmiddelen en nieuwe infrastructuur kunnen de groter wordende verkeerstromen in goede banen leiden en hoe ziet het vliegtuig (auto, fiets, snelweg etc.) van de toekomst er uit?
Wat is de invloed van toenemende virtuele infrastructuur op de behoefte aan fysieke infrastructuur?
Hoe kunnen vervoer en leefomgeving met elkaar geïntegreerd worden?
Leidt de ontwikkeling van zelfrijdende auto's uiteindelijk tot versmelting van openbaar en privaat vervoer?

Science for Society
Wat is de rol van de mens in het vervoer in 2050; als actieve bestuurder of passieve passagier?
Hoe kunnen verschillende vervoerssystemen optimaal met elkaar verbonden worden (multimodale knooppunten)?
In hoeverre kan infrastructuur hindervrij, en zonder barrièrewerking, in de gebouwde omgeving ingevlochten worden?
Hoe kunnen de paradoxale eisen aan infrastructuur, robuustheid en flexibiliteit, met elkaar gecombineerd worden.
Wat zijn de juridische en verzekeringstechnische consequenties van autonoom rijden?

Science for Competitiveness
Welke investeringen in infrastructuur/ leidingen/vaarwegen zijn nodig om Nederland de vervoerder van Europa te laten blijven?
Hoe kan de zee gebruikt worden om energie op te wekken, zonder visueel of fysieke vervuiling te veroorzaken?
Hoe kunnen parkeerproblemen op drukke locaties opgelost worden?
Hoe kunnen files voorkomen, of tenminste gereduceerd, worden?
Zijn luchthavens hindervrij en duurzaam te integreren in dichtbevolkte gebieden?

Science for Science
Hoe zullen robotica en 3D printen het bouwen gaan beïnvloeden?
Kunnen constructies door een combinatie van slim monitoren en tijdige onderhoudsingrepen, in de toekomst eeuwig meegaan? Welke informatie is hiervoor nodig?
Hoe ziet een toekomstbestendige virtuele infrastructuur er uit?
Waartoe leidt verdergaande automatisering van bouwprocessen (o.a. prefabricage)?
Hoe kunnen stamcel-materialen ontwikkeld worden, d.w.z. materialen die zich aanpassen aan de omgevingseisen?

Science for Society
Hoe kunnen verschillende systemen en installaties duurzaam en aanpasbaar geïntegreerd worden in gebouwen en infrastructuur?
Hoe kan door monitoring en reporting de veiligheid van de (bestaande en toekomstige) gebouwde omgeving verbeterd worden?
Hoe kunnen big data analyses gebruikt worden om sociale en culturele processen in de gebouwde omgeving te ondersteunen?
Hoe kan door middel van slim gebruik van data de hoeveelheid afval in een bouwproces verminderen?

Science for Competitiveness
Hoe kan door middel van serious gaming en andere virtual reality technieken het bouw-, beheer- en gebruiksproces worden verbeterd?
Welke financieringsarrangementen zijn nodig voor het toepassen van innovatieve technologische toepassingen?
Welke nieuwe beleidsvormen (juridisch en regelgeving) zijn nodig om de automatisering van bouwprocessen te ondersteunen?
Hoe kan voorkomen worden dat bij het uitvallen van de elektriciteitsvoorziening de volledige virtuele infrastructuur plat komt te liggen?

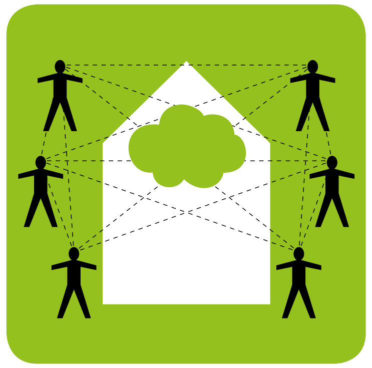
INFORMATIE & INTERACTIE: INTELLIGENTIE IN DE BOUW

De bebouwde omgeving bepaalt in belangrijke mate ons gevoel van welzijn. In een wereld van toenemende automatisering neemt het gebruik van robotica en ICT ook in de bouw toe. Dit leidt tot een virtuele infrastructuur die ver-schillende partijen en processen met elkaar verbindt, en bovenal een enorme hoeveelheid data en informatie produceert. Dit zal de manier van bouwen, de bouwplaats en daaraan gekoppelde processen ingrijpend gaan veranderen.

De digitalisering van de bouw staat nog in de kinderschoenen. Met technolo-gische innovaties en het beschikbaar komen van steeds meer informatie, zal op het gebied van het bouwproces, ketensamenwerking en –integratie nog veel winst te behalen zijn. Ontwikkelingen zoals BIM, 3D-printing, sensors en drones zullen talrijke mogelijkheden bieden voor constructie en duurzaam beheer van onze leefomgeving. De integratie van verschillende informatie systemen en real-time data communi-catie leidt momenteel echter nog tot veel problemen.

Daarnaast ontstaan nieuwe vraagstukken over de balans tussen openbaar en privé. De beschikbare hoeveelheid data gerelateerd aan de bouw is al enorm, en zal naar verwachting blijven groeien? Welke informatie hebben we nodig, en hoe wordt die informatie gedestilleerd uit data-sets? Welke data zijn er in de toekomst nodig, en kunnen we daar nu al op anticiperen? Hoe gaan we de informatie delen, binnen bouw- en beheerprocessen, met beleidsmakers en eindgebruikers? Data science is daarom bij uitstek een kennisgebied dat de toekomst van de bouw en het beheer van de (openbare) ruimte gaat bepalen.

Momenteel ontbreekt het nog aan informatie en inzicht over de kansen en toepassingen van ICT ten behoeve van bijvoorbeeld het klimaat in gebouwen, comfort, gezondheid, welzijn en bovenal de menselijke interactie met technische systemen in gebouwen. Een sterke kennispositie over de inpassing van systeem innovaties in de gebouwde omgeving en effectieve toepassing van ICT in de bouw, zal de concurrentiepositie van Nederland blijvend kunnen versterken.



INTEGRATIE & ORGANISATIE: SMART CONSTRUCTION

Opdrachtgeverschap en projectmanagement in de bouw worden in toenemende mate complex. In alle projectfasen, vanaf initiatief en ontwikkeling tot aan realisatie en beheer, zijn multi-disciplinaire, multi-stakeholder en multifunctionele processen geen uitzondering meer. Voor de 'license to operate' zal de bouwsector haar opdrachtgevers, omgeving en ketenpartners meer betrouwbaar en reëler tegemoet moeten treden. Verder is er een beweging richting meer zelfbouw en meer bouw op kleine schaal. Daarnaast wordt de bouwsector meer bipolair, met enkele grote spelers, en vele kleintjes.

Door de economische crisis is een ontwikkeling in gang gezet richting een veel kleinschaligere bouw. Economische groei moet nu gezocht worden in iets anders dan enkel het bouwvolume. Hiervoor zullen onder andere nieuwe markt-partijen en financieringsarrangementen nodig zijn. Er kan gedacht worden aan andere business modellen zoals huren in plaats van kopen, of financiering door middel van crowd funding. Daarnaast wordt transparantie van beleid en besluitvorming steeds belangrijker en wordt in toenemende mate waarde gehecht aan creativiteit en waarde creatie.

De toegenomen complexiteit van het bouwproces leidt tot nieuwe onzekerheden op het gebied van planning, kosten, tijdige voltooiing en uiteindelijke kwaliteit van het bouwwerk. Opdrachtgeverschap en de relatie met opdrachtnemers verandert en risico's verschuiven. Aan de ene kant worden opdrachtgevers en gebruikers ontzorgd; aan de andere kant krijgen stakeholders juist steeds meer zeggenschap in bouwprocessen. Zo ontstaan nieuwe werkvormen, zoals ketensamenwerking en integrale werkwijzen, met een heel scala aan nieuwe management uitdagingen van dien.

Een andere trend is de netwerk benadering ten aanzien van infrastructuur; er worden immer hogere eisen gesteld aan betrouwbaarheid van netwerken en voorzieningen. Verder liggen er grote uitdagingen met betrekking tot onderhoud en beheer. Voortgaand wetenschappelijk onderzoek is nodig naar nieuwe aanbestedings- en contractvormen, regelgeving, juridische kaders en financieringsmodellen. Hoe kan Nederland een gidsland worden op het gebied van lange termijn samenwerking en waarde creatie?

Science for Science
Hoe ontwikkelen we inclusieve (multi-stakeholder), coöperatieve werkwijzen voor stedelijke ontwikkeling?
Hoe kunnen methodes zoals Life Cycle management toegepast worden op processen die de duur van een mensenleven ver overstijgen?
Hoe kunnen moeilijk kwantificeerbare kwaliteitsaspecten van de gebouwde omgeving gebruikt worden in aanbestedingsprocedures (best value procurement)?
Hoe moet de bouwlogistiek georganiseerd worden zodat nergens in de keten meer voorraden nodig zijn?

Science for Society
Wat is de toekomstige rol van verschillende (interne en externe) stakeholders in bouwprocessen, en hoe kan hier het best mee worden omgegaan?
Hoe kan binnen ketensamenwerking 'data op maat' met elke ketenpartner gedeeld en teruggekoppeld worden?
Ketensamenwerking: hoe is duidelijk waar verantwoordelijkheden en risico's liggen bij steeds dichtere samenwerking?
Wat voor opleidingseisen en expertise heeft de bouwer, projectmanager, architect en eindgebruiker in de toekomst nodig?

Science for Competitiveness
Hoe kan het investeren in lange termijn oplossingen aantrekkelijker gemaakt worden en welke financiële constructies zijn hiervoor nodig (o.a. wanneer terugverdientijd > 100 jaar is?
Welke nieuwe contractvormen zijn nodig als we overstappen naar huur van materialen en services in plaats van kopen, of naar financiering middels crowd sourcing?
Hoe kan kleinschaligheid kosteneffectief worden?
Is een aanvullend juridisch kader nodig voor ketensamenwerking en hoe moet deze ingericht worden?

ENERGIE & GRONDSTOFFEN: CIRCULAR ECONOMY

Onze huidige leefwijze legt een onevenredig groot beslag op schaarser wordende grondstoffen, water, ruimte en energie. Deze levenswijze gaat gepaard met belasting van de leefomgeving: CO2 en andere afvalgassen in de lucht – leidend tot klimaatverandering –, vervuiling van oppervlakte- en grondwater, contaminatie van de bodem door storten van afval. Een groot deel van deze milieubelasting wordt veroorzaakt door de bouw. Het realiseren van een toekomst gebaseerd op duurzaam materiaal- en energiegebruik in de bouw is daarom van groot belang voor toekomstige generaties.

De mens legt een steeds groter beslag op eindige hulpbronnen: fossiele energie en grondstoffen. Dit heeft grote impact op zijn leefomgeving. De bouw legt een groot beslag op grondstoffen en energie; zo leidt de productie van cement alleen al tot 5% van de jaarlijkse CO2 –uitstoot. De bouw werkt met gefragmenteerde processen die geen rekening houden met de lange termijn milieubelasting en levensduur en hergebruik van materialen. De implementatie van een circulaire economie zou hier oplossingen kunnen bieden.

In een circulaire economie worden de belasting op het milieu en de kosten van beheer van de gehele levensduur van producten meegenomen en wordt gekeken hoe materialen en energie (eeuwig) hergebruikt kunnen worden met hetzelfde kwaliteitsniveau. Deze circulaire aanpak verschuift de focus van nieuwbouw naar hergebruik en richt zich op een omschakeling naar een bouwsector die geen afval meer produceert. De uitdaging is om voor zeer lange gebruiksperiodes te ontwerpen, met inherent functionele flexibiliteit van de bouwwerken. De implementatie van nieuwe, circulaire processen als de basis voor een duurzame bouw is echter uitermate ingewikkeld.

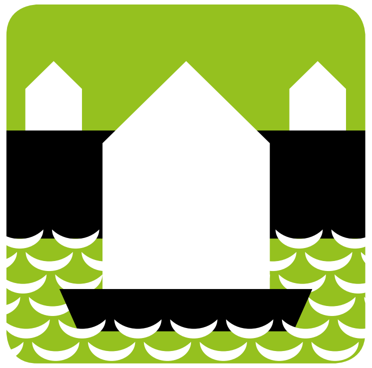
De mogelijkheden voor het produceren van hernieuwbare energie en duurzame materialen zijn nog maar ten dele bekend. Daarnaast is er ook veel onderzoek nodig op procesniveau: nieuwe werkvormen, aanbestedingsprocedures, business modellen voor levensduur benadering of building with nature. Tenslotte zal het energielandschap veranderen van grootschalige installaties, naar decentrale productie. Kortom, de noodzakelijke energietransitie zal vergaande consequenties hebben voor de bebouwde omgeving.

Science for Science
Hoe kunnen gebouwen, constructies es en materialen flexibel hergebruikt worden?
Hoe ontwikkelen we materialen, voor veiligere en meer duurzame constructies, die niet verouderen, en liefst beter en sterker worden in de tijd?
Hoe kunnen de huidige afvalbergen gerecycled of hergebruikt worden als grondstof voor nieuwe materialen, ofwel: hoe maken we de stap van 'duur slopen' naar 'urban mining'?
Hoe kan 3D printen ingezet worden zodat minder materiaal en energie gebruikt wordt tijdens de bouwproductie?

Science for Society
Hoe kan het gebruik van materialen en energie verminderd worden zonder op functionaliteit of comfort te hoeven inleveren?
Hoe motiveer je blijvend zoveel mogelijk mensen om mee te doen aan de 'circular economy'?
Hoe kan het circulair ontwerpen van producten de standaard worden?
Hoe kunnen robotica en automatisering materiaal- en energie-efficiëntie vergroten?
Hoe moeten bestaande gebouwen en stedelijke gebieden aangepakt worden om energetische prestatie radicaal te veranderen?

Science for Competitiveness
Welke incentives en subsidies nodig om de circulaire economie mogelijk te maken?
Hoe kan het energienetwerk voorbereid worden op een sterk fluctuerende vraag en aanbod van duurzaam opgewekte energie?
Hoe kunnen de laatste restjes fossiele brandstoffen gebruikt worden om volledig over te stappen op duurzame brandstoffen?
Hoe kan het duurzame gebruik van de ondergrond gemonitord en gemanaged worden?
Hoe kan windenergie in de bebouwde omgeving rendabel worden?

ANTICIPATIE & ADAPTATIE: KLIMAAT



Vooral vanwege economische redenen trekken mensen steeds meer naar steden toe, steden die om dezelfde reden vaak in deltagebieden of aan grote rivieren liggen. Deze gebieden zijn extra kwetsbaar voor extreme weersomstandigheden. Klimaatverandering leidt vooral tot toename van deze extremen: wateroverlast, stormen en tornado's, extreme koude die het openbare leven verlamt, extreme droogtes die sanitatie, watervoorziening en stabiliteit van de ondergrond bedreigen, en periodes van extreme hitte die industriële productieprocessen stilleggen en tot verhoogde sterfte onder ouderen leiden.

Door klimaatverandering zal de frequentie van extreme weersomstandigheden blijven toenemen. Retentie en nuttig gebruik van regenwater wordt steeds relevanter en vraagt om een goede waterplanning van stedelijke gebieden als onderdeel van integraal watermanagement, welke wellicht te koppelen is aan een duurzame energievoorziening. Verder is het de vraag hoe de met wateroverlast gepaard gaande risico's verzekerd gaan worden. Kunnen cruciale installaties of woningen en infrastructuur in zeer overstromingsgevoelige gebieden niet beter worden uitgerust met intrinsiek 'drijfvermogen'?

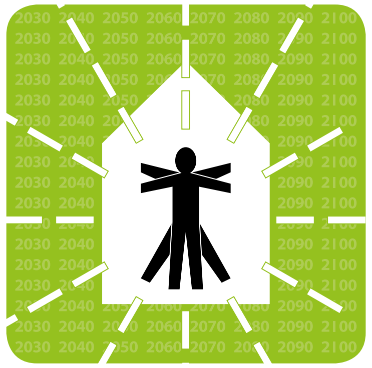
Hier en daar zou het wellicht zelfs profijtelijk kunnen zijn het land, of alleen de infrastructuur en gebouwen te verhogen. Als Nederlandse steden niets doen aan hun klimaatrobuustheid zullen ze binnen enkele decennia 's zomers een klimaat vergelijkbaar met dat rond de Middellandse Zee hebben, hetgeen grote gevolgen voor de volksgezondheid met zich meebrengt. Het in stedelijk gebieden temperen van temperatuurextremen is van groot belang, en biedt tevens een mogelijkheid om buffers (warmte accu's) te implementeren, waarmee de gevolgen van temperatuur-schommelingen over langere periodes uitgesmeerd kunnen worden en eventueel benut.

Extreme omstandigheden vragen ook om nieuwe ontwerpstrategieën en materialen voor wegen, bruggen en tunnels. Deze dienen robuust en betrouwbaar te blijven functioneren. Dit alles vraagt niet alleen om het vergroten van de voorspelbaarheid van het gedrag van materialen, constructies en systemen, maar ook van het weer en andere natuurfenomenen, zoals aardbevingen en vulkaanuitbarstingen. Zelfs als de vermeende oorzaken van klimaatverandering in de komende decennia volledig kunnen worden weggenomen, dan nog zullen de gevolgen zich lang merkbaar zijn.

Science for Science
Hoe kunnen steden voorbereid worden tegen extreme omgevingsomstandigheden (wateroverlast, hitte, maar ook aardbevingen)?
Hoe kunnen extreme weersomstandigheden (en andere natuurlijke fenomenen) en de effecten daarvan, nauwkeurig voorspeld worden
Hoe kan het klimaat in Nederlandse steden op een dusdanige manier worden beheerst dat tegelijkertijd een duurzamer energiesysteem wordt gerealiseerd?
Hoe ontwikkelen we klimaat-robuuste materialen en constructies (vorst en hitte bestendig)?

Science for Society
Hoe kan de Nederlandse gebouwde omgeving waterveilig worden gemaakt, onderwijl bijdragend aan een effectievere inzet van water in het dagelijks gebruik?
Hoe maken we doeltreffende en precieze voorspellende modellen voor waterveiligheid?
Hoe te anticiperen op grote hitte en extreme koude?
Hoe kan door bufferen het effect van droge/natte periodes gemitigeerd worden?
Hoe kunnen lokale overschotten, bijvoorbeeld van water of 'hitte', op plekken waar hieraan schaarste is worden ingezet?

Science for Competitiveness
Wat is de relatie tussen water en stedelijke vernieuwing en ontwikkeling (watersteden, bereikbaarheid etc.)?
Kan biological engineering van materialen en 'bouwen met de natuur' leiden tot oplossingen die kunnen concurreren met traditionele technieken (bijvoorbeeld bacteriën injecteren in dijken)?
Hoe kunnen we gebouwen en infrastructuur ontwerpen die meeleven/aanpassen aan het klimaat?
Zorgen dat Nederland niet onderstroomt: hoe gaat een nieuw Deltaplan er uitzien, en hoe kan deze kennis over waterbouw en waterveiligheid ook voor andere landen nuttig zijn?



Science for Science
Welke beleidsmaatregelen of andere triggers zijn er nodig om snel tot een grootschalige gedragsverandering te komen en hoe kan de overheid hier een gidspositie innemen?
Hoe kan het ontwerpproces zo ingericht worden ten einde de optimale implementatie van energie- en materiaal-efficiënte technologieën te garanderen?
Hoe kan het 'internet-of-things' helpen de doelstellingen ten aanzien van energie efficiency van gebouwen en infrastructuur te verwezenlijken?

Science for Society
Hoe kunnen eigenaren van objecten in de gebouwde omgeving gestimuleerd worden om de kwaliteit van het object , dwz. energie-consumptie, onderhoud, aanpasbaarheid, leefklimaat etc., up-to-date te houden?
Hoe kan van de stedelijke omgeving een ecologische hoofdstructuur gemaakt worden?
Hoe kan het cyclische karakter van de vastgoedmarkt, welke leidt tot verwaarloosde gebieden en leegstand en verpaupering in de stad, doorbroken worden?
Hoe kunnen gemeenschappen collectief rentmeesterschap ontwikkelen ten aanzien van duurzame kwaliteit van alle aspecten van hun omgeving?

Science for Competitiveness
Hoe kunnen wetenschappelijke onderzoeksresultaten en toepassingen daarvan, sneller de markt bereiken?
Hoe kunnen we prestaties van klimaatafhankelijke (gebouw)innovaties in een Europese landkaart weergeven, zodat het product op meest efficiënte locaties kan worden verkocht?
Hoe kunnen life cycle prestaties van materialen en constructies objectief worden gemeten, gedissemineerd en toegepast?
Hoe kan nu al verdiend worden aan lange termijn oplossingen die voor toekomstige generaties geïmplementeerd worden?

INTEGRATIE VAN INNOVATIE: THE FUTURE STARTS NOW

De meeste innovaties uit diverse wetenschappelijke disciplines vinden hun toepassing uiteindelijk in de gebouwde omgeving: in woningen, kantoren, fabrieken, bruggen, wegen, vliegvelden en hun installaties. De hoeveelheid aan ontwikkelde innovaties is enorm. Tegelijkertijd is het mogelijk dat bestaande optimale situaties weg-geïnnoveerd zijn: vervangen door iets nieuws dat niet noodzakelijk beter is. Wie kan dit allemaal overzien? Hoe meet en weeg je het belang van een ontwikkeling alvorens deze grootschalig toegepast is en er langdurig ervaring mee is opgedaan?

Ontwikkelingen die lange termijn voordelen bieden, die zich uitstrekken voorbij de sterfelijkheidhorizon van individuen, kunnen grote impact op de mensheid hebben. Maar de economie van de vrije markt is (nog) niet ingericht op voordelen en cash flows in een verre toekomst. Hoe kun je in het hier en nu bepalen of een technologie of beleidskeuze op zo'n lange termijn voordelen biedt? Verder blijven er talrijke veelbelovende technologieën 'op de plank liggen'. Alleen grootschalige toepassing gedurende langere tijd kan aantonen of een nieuwe technologie echt werkt, wat vervolgens de mogelijkheid geeft tot door- en uitontwikkeling en tot optimalisering van voordelen.

Dit vraagt echter om partijen die grootschalige risico's willen en kunnen dragen, partijen die vooroplopen en sturen. Zijn dat de overheden, internationale verbanden, NGO's?

De uitdagingen van vandaag zijn te groot om alleen maar door technische oplossingen beslecht te kunnen worden. Er zal een zeer breed gedeeld gevoel van noodzaak moeten ontstaan, er zullen snelle resultaten nodig zijn om het momentum te houden en te vergroten.

Er zal sturing moeten plaatsvinden, naar kennisbehoefte, de 'fog of information' over de prestatie van diverse alternatieve innovaties zal moeten optrekken. Innovatie vraagt om toepassing, testen in de praktijk, verwerpen of evolutionair verbeteren. Het vraagt intense samenwerking om technieken en processen verdergaand te integreren en te versimpelen. Dit gebeurt allemaal door mensen: hoe bereid je mensen in onderwijs en inspiratie voor op zo'n gezamenlijke uitdaging?

BUILT SOCIETY SMART REALITY

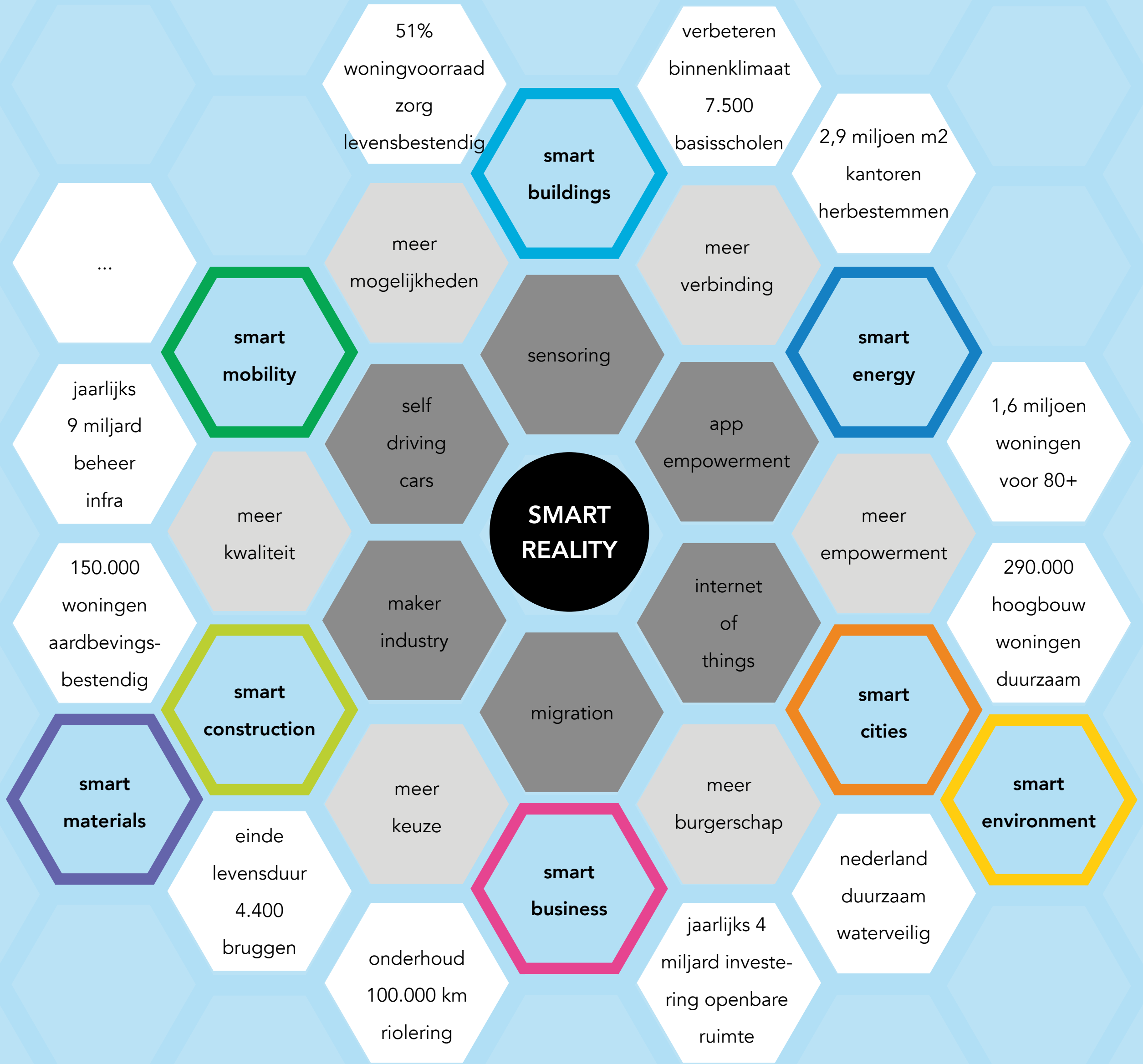
Gedreven door een zich steeds sneller ontwikkelende technologie verandert de wereld continu en ingrijpend. Ze wordt niet langer gestuurd door een centrale visie of beleid, maar gedreven door spontaan en breed gedragen gebruik van opkomende technieken en diensten.

De bouw transformeert van 'traag', 'traditioneel' en 'hardware' naar 'flexibel', 'innovatief' en 'programmeerbaar'

BUILT SOCIETY geeft inzicht in de achtergronden, ambities en plannen van de bouwsector als samenwerkende en betrokken professionals; van onderzoekers en ontwerpers, tot aannemers, adviseurs, gebruikers, beleidsmakers, etc.

SMART REALITY toont de relatie tussen actuele ontwikkelingen in de maatschappij en de impact hiervan voor de gebouwde omgeving. Het laat de complexe relaties tussen trends, thema's, en gedeelde ambities zien. De bouw moet hier, door uitwerking van specifieke projecten, adaptief en anticiperend op inspelen.

Enkele concrete TODO's - nieuwe initiatieven en projecten in uitvoering - laten zien hoe effectieve kennisontwikkeling en -uitwisseling tot stand komen. Intelligente strategieën worden ontwikkeld, en in onderzoek en praktijk opgepakt om zo effectief vorm te geven aan 'built society'.



OPGAVEN

THEMA'S

EFFECTEN

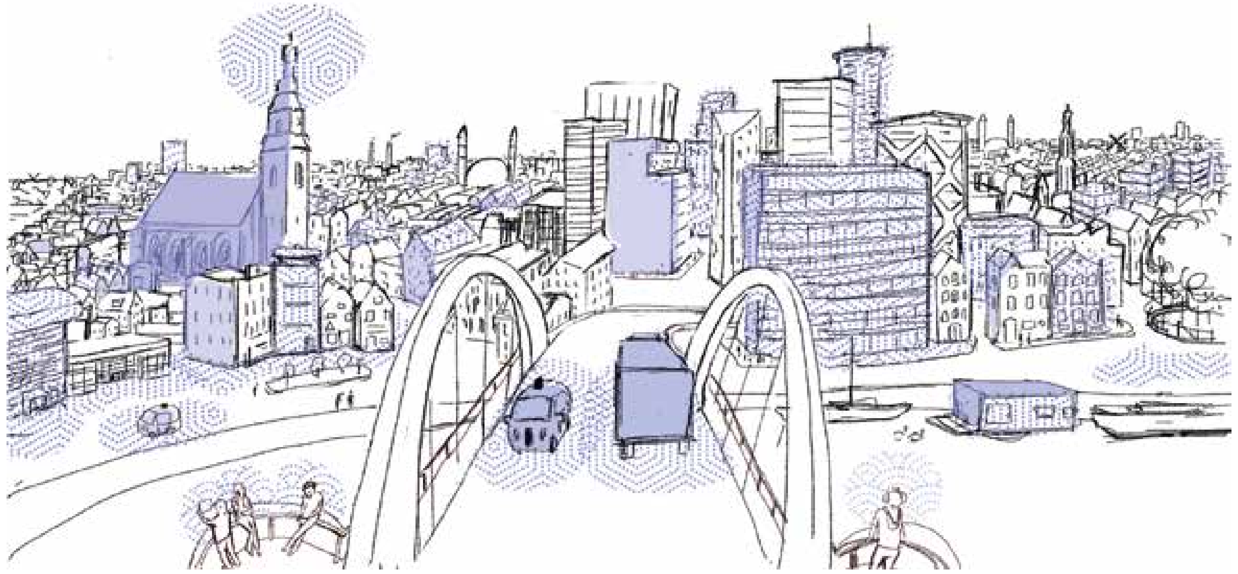
TRENDS

in collaboration with
Bouwend Nederland and De Bouwcampus

Content
Siebe Bakker, Dré Kampfraath, Patrick Koimans, Alexander Schmets

Graphic design
Siebe Bakker, Mariet Sauerwein

Initiative
3TU.Bouw, Bouwend Nederland, De Bouwcampus



WELKOM IN DE SLIMME STAD

Een reeds lang ingezette, en wereldwijde, trend is die van de toenemende concentratie in stedelijke gebieden (metropolen) en omliggende regio's, terwijl elders juist regio's leeglopen en krimpen. In 2050 zal zo'n 70% van de wereldbevolking in een stedelijke omgeving wonen, die dan goed zijn voor bijna 80% van het bruto wereldproduct (global GDP). De trend van toenemende verstedelijking lijkt onstuitbaar, en vanuit efficiency optiek ook verklaarbaar: stedelijk leven leidt tot schaalvoordelen. Zo zal bij een verdubbeling van de stedelijke bevolkingsomvang slechts 85% extra infrastructuur nodig zijn. Maar de stad is ook een concentratie van mensen, die streven naar comfort en gemak, maar vooral een vervuld en plezierig leven willen leiden, waarin gezondheid, sociaal contact, geborgenheid, verbondenheid, individuele ontplooiing maar ook 'ergens bij horen', etc., voorop staan; bruto stedelijk geluk. De nieuwe, zich steeds sneller ontwikkelende digitale verbinding tussen mensen onderling, tussen mens en omgeving, en tussen objecten onderling – de digitale laag, een nieuwe dimensie van de stad die het aspect smart laadt -kan zorgen voor extra schaalvoordelen van het leven in de stad. Tegelijkertijd zal dit leiden tot versterking van de economische vitaliteit èn leefbaarheid van de stad. Overigens, de inwoners van krimp- en buitengebieden zullen vanzelfsprekend profiteren van dezelfde 'smart technologieën' die smart cities leefbaar en dynamisch maken.

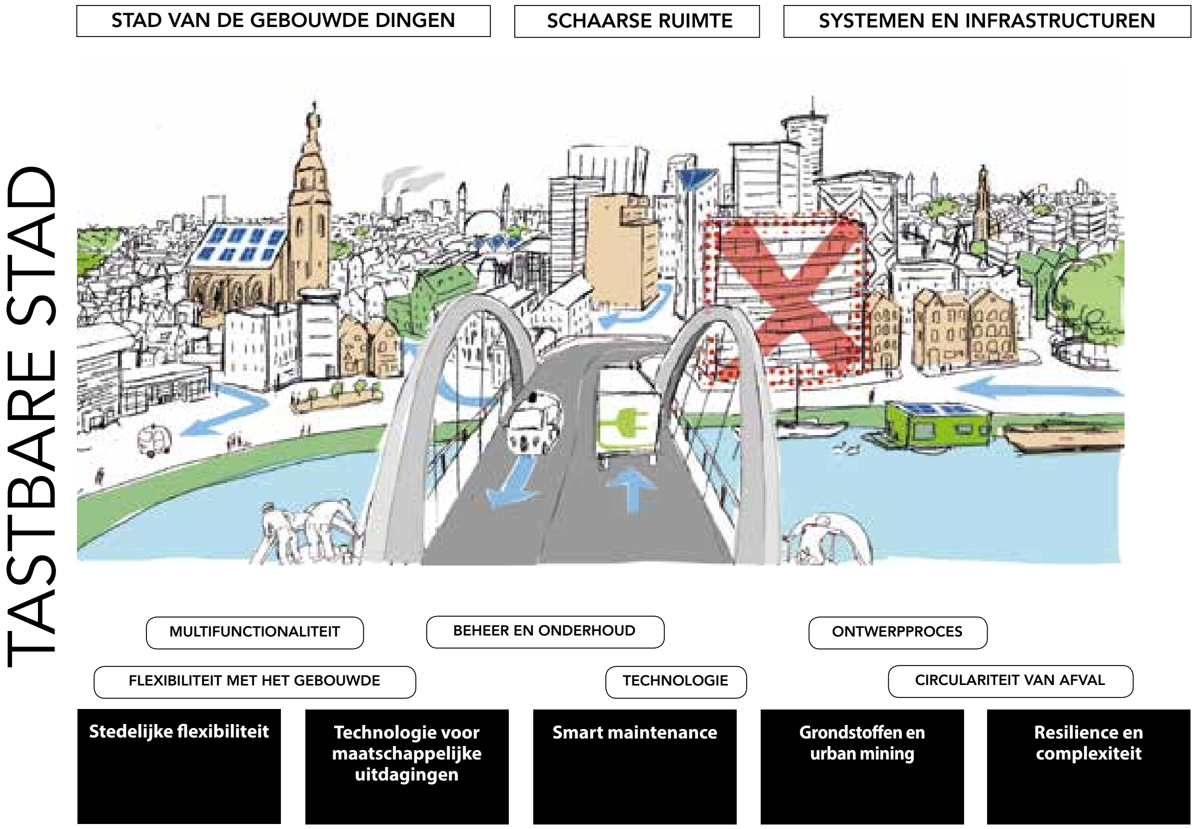
Kortom, het stedelijk leven wint steeds meer aan belang; een aanzienlijk deel van de sociale interactie, innovatie en culturele ontwikkeling vindt hier plaats. De verdichting, die inherent is aan het stedelijk leven, brengt echter ook aanzienlijke maatschappelijke uitdagingen met zich mee, die zich manifesteren op verschillende schaalniveaus (gebouw, buurt, wijk, stad, regio, land). Deze zijn door veelheid aan onderlinge interacties en onderlinge verwevenheid complex van aard. Naast genoemde maatschappelijke uitdagingen, is een adequaat antwoord op de schaarste-problematiek rond (openbare) ruimte, schoondrinkwater, voedselproductie, een schoon en gezond milieu, energie en grondstoffen, cruciaal voor het uitbouwen van het succes van de stad als gunstig biotoop voor de mens, en andere levensvormen. Daarnaast bepalen lange termijn ontwikkelingen, zoals klimaatverandering, demografische bewegingen (o.m. vergrijzing en vergroening), voortgaande digitalisering en toenemende individuele mobiliteit, de houdbaarheid van het stedelijk succes. Dit vraagt om antwoorden die een geïntegreerde aanpak vereisen op zowel technisch, sociaal, ecologisch en economisch vlak. Er zal daarbij uitgegaan moeten worden van de bestaande stad; de bestaande gebouwde omgeving, de bestaande inwoners van een stad, de bestaande stadsecologie en de institutionele structuren zijn een gegeven.

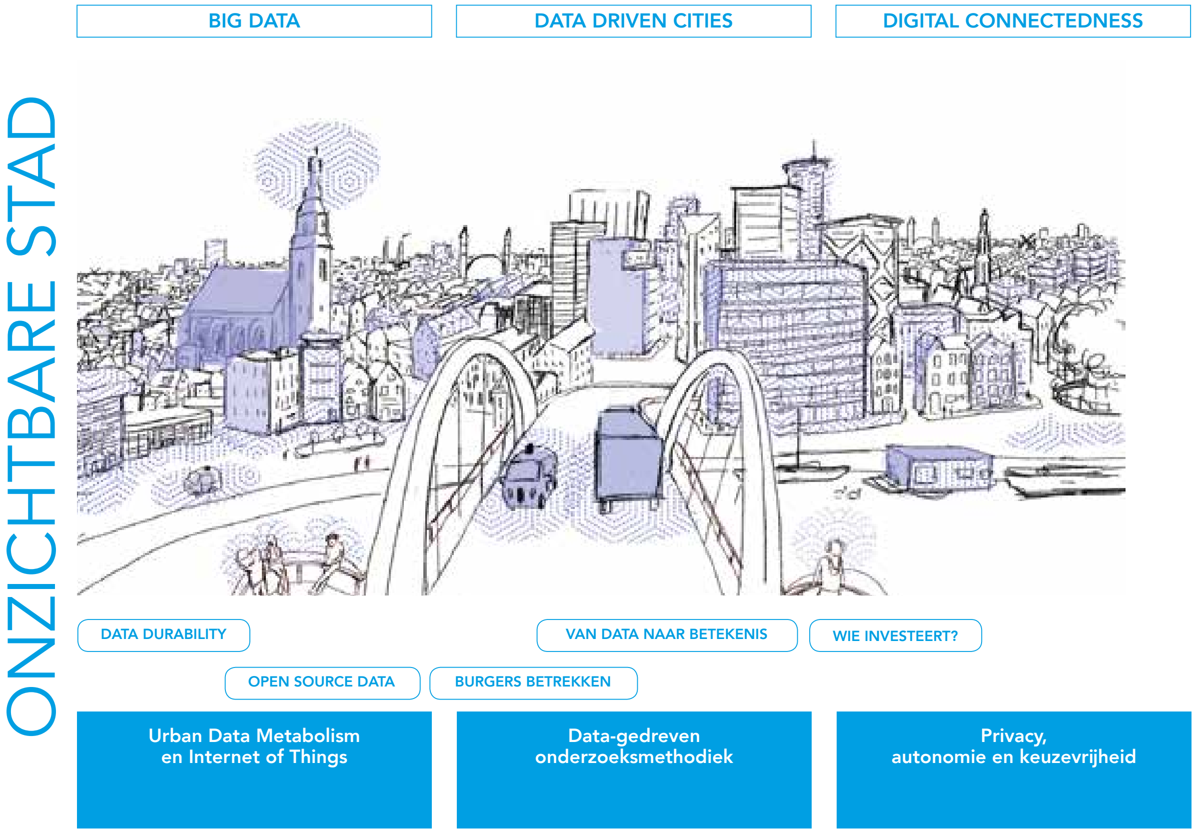
De NWA-route Smart, liveable cities staat een integrale, multidimensionale aanpak voor, waarbij zowel de kansen als de bedreigingen voor de stad worden geadresseerd, voor nu en voor later. Daarvoor zijn nieuwe samenwerkingsvormen nodig, waartoe de diverse vakgebieden hun krachten bundelen, naar elkaar luisteren en van elkaar leren. Om in gezamenlijkheid te anticiperen en nieuwe contouren te schetsen voor een wereld, en een stad, waar het goed leven is voor de mens, zo goed mogelijk in harmonie met zijn natuurlijke omgeving. Een stedelijk leven ondersteund door recente verworvenheden op het gebied van communicatie en interactie: welkom in de leefbare, dus slimme, stad!

Belang en urgentie

De stad is bij uitstek het schaalniveau waarop belangrijke maatschappelijke uitdagingen zich manifesteren en is daarmee in al zijn facetten van belang als het aggregatieniveau waarop toekomstig fundamenteel, toegepast en praktijkgericht onderzoek gericht zal zijn. De stad is dé context waar veel kennis en technologieën uiteindelijk geïntegreerd en toegepast worden. Dat vereist een interdisciplinaire benadering van alle stakeholders, om samen effectieve verander- en aanpassingsstrategieën te ontwikkelen, zowel technisch als niet-technisch; ook al om op positieve wijze een synthese van het nieuwe met het bestaande te bewerkstelligen. De urgentie van deze route is evident: het toekomstbestendig maken van steden, en hun buitengebieden, vereist het herdefiniëren van de samenhang tussen bestuursmodellen, veranderende betrokkenheid van burgers en bedrijven, toenemende betekenis en ontwikkeling van technologie, zuiniger en circulaire energie- en grondstofgebruik, klimaatadaptatie, benutten van digitalisering voor veilig en goed functionerende steden en het verbeteren van het stedelijke ecosysteem. Veel meer dan in het verleden zal dit geschieden op het speelveld waar de stad, haar burgers, bedrijven, instituties en (gelegenheids-)coalities met elkaar interacteren.

De bestaande stad is het levend laboratorium waar de toekomstige stad en haar relatie met de wereld eromheen vorm krijgt.





in collaboration with
Bouwend Nederland,
De Bouwcampus, and others

Trekkersgroep
TS Energie, TKI Urban Energy
Teun Bokhoven
VNO-NCW / Bouwend Nederland
Tom van Eck
Bouwend Nederland
Patrick Koimans
4TU.Bouw
Alexander Schmets
Erasmus Universiteit Rotterdam
Liesbet van Zoonen

Inforgraphics
Dré Kampfraath & Frans Schupp

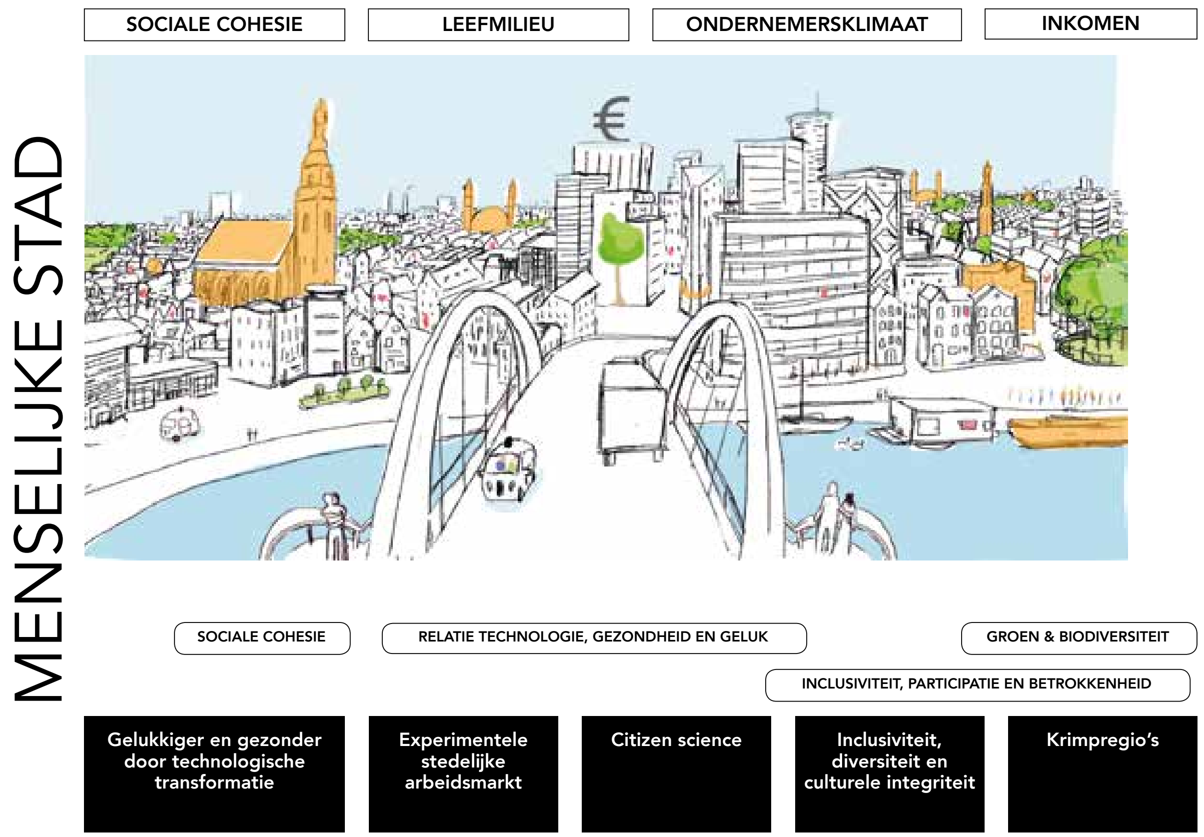
Voorbereidingsgroep
Wageningen UR **Carmen Aalbers,**
Jan Vreeburg
Nationaal Regieorgaan Praktijkgericht
Onderzoek Sia **Martje van Ankeren**
Universiteit van Amsterdam
Luca Bertolini
Nationale Wetenschapsagenda
Colette Bos
Technische Universiteit Delft
Geert-Jan Houben
TNO **Kees d'Huy,**
Peter Paul van 't Veen
NWO **Marcus van Leeuwen**
Vereniging Hogescholen / Haagse
Hogeschool **Vincent Smit**
NIOO-KNAW **Kamiel Spoelstra**
Universiteit Twente
Maarten van Steen
Vereniging Hogescholen
Sandra Storm

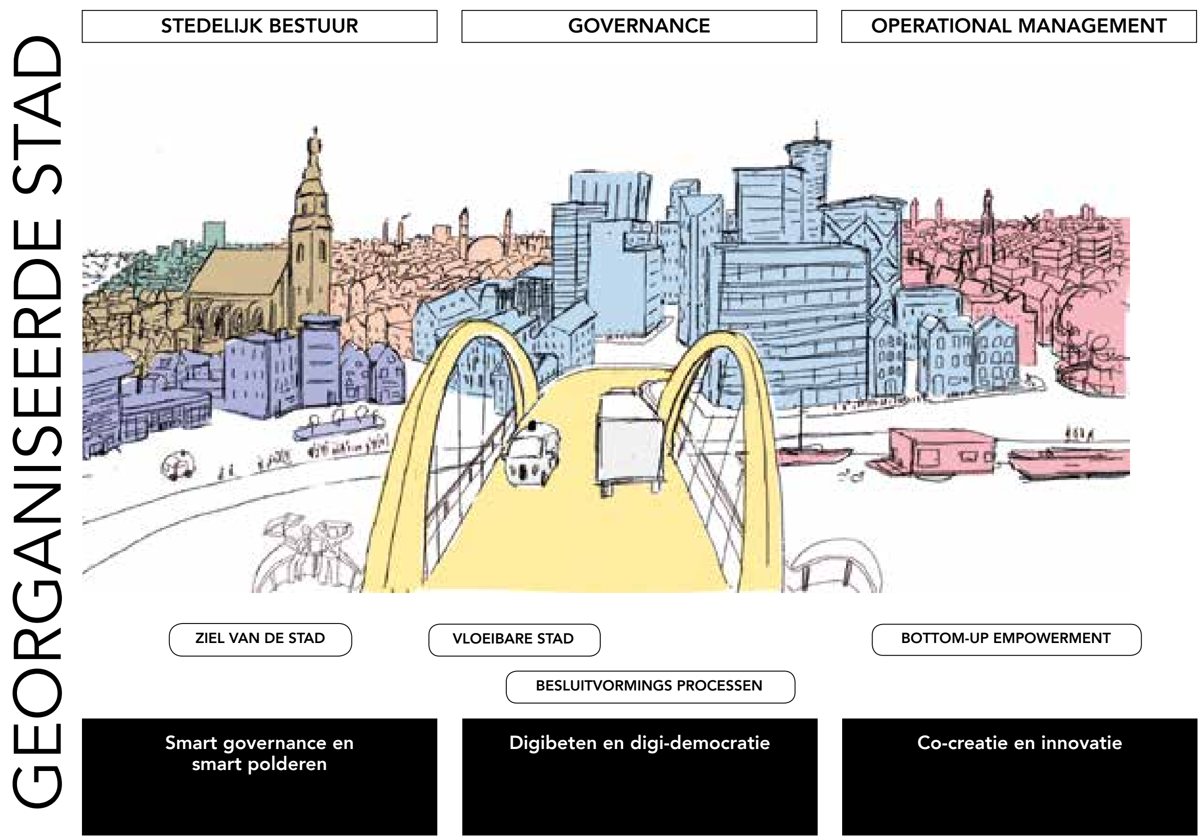
Vernieuwende verbindingen

Een viertal deelperspectieven ten aanzien van de zich ontwikkelende stad is gebruikt om de brede scope en het verband tussen de vele en diverse aspecten binnen deze route, te identificeren. Vanuit de verscheidenheid aan wetenschappelijke disciplines, was het uitgangspunt om maximaal vernieuwende verbindingen tussen disciplines, instituten, tussen wetenschap, maatschappij en bedrijfsleven te identificeren en samen te brengen.

De samenhang tussen de deelperspectieven is in essentie de uitdaging waartoe onderzoekers, onderzoeksinstellingen, bedrijfsleven en andere stakeholders gesteld zijn. Samenwerking en nieuwe verbindingen zijn noodzakelijk om de diverse deelperspectieven door nieuwe inzichten, technologieën en bestuursarrangementen te doen convergeren naar een leefbare stedelijke omgeving voor zoveel mogelijk mensen.

- Menselijke Stad – Zonder mensen geen stad. Alleen met een optimaal leefklimaat voor mensen kunnen steden floreren. Mensen moeten gezond, gelukkig, veilig en met elkaar kunnen leven. Aandacht voor een goed leefmilieu,sociale cohesie, inclusiviteit, betrokkenheid, een toereikend inkomen en een gezond ondernemersklimaat zijn hierbij van belang.
- Georganiseerde Stad - De huidige, snelle technologische ontwikkelingen zullen ook verstrekkende gevolgen hebben voor de organisatie van steden. Nieuwe technologie geeft nieuwe mogelijkheden voor participatie in besluitvorming, en andere vormen van communicatie en samenwerking tussen bestuursorganen, onderling en met burgers en belangengroepen mogelijk maken. Het is daarom van groot belang beter inzicht te krijgen in de organisatie - en politieke structuur - van steden, hoe deze zich ontwikkelen en wat de consequenties zijn van de steeds grotere beschikbaarheid en invloed van nieuwe technologie.
- Onzichtbare Stad - Veel, met name digitale, ontwikkelingen in smart cities onttrekken zich aan het blote oog. Sensor- en registratietechnologie, sociale media en e-government vormen een nieuwe, digitale data laag in de stad. Dat vraagt om herbezinning op verhoudingen, inrichting en 'governance' van deze nieuwe laag, en het nieuwe spanningsveld tussen privacy en publiek belang. Privacy en (cyber)veiligheid zijn basiswaarden om de smart city ook liveable te houden.
- Tastbare Stad - Een stad is ook een verzameling van gebouwde dingen, van systemen en infrastructuren (zoals verkeer, data, energie, groen en water) die samen beslag leggen op een deel van de schaarse ruimte van een stad, voor kortere of juist zeer lange tijden. De toenemende druk op de stad vraagt om fysieke innovaties die veranderende mobiliteits-patronen, in het stedelijk weefsel geïntegreerd duurzaam gebruik van energie en grondstoffen, klimaatbestendigheid, diversiteit, gezondheid, demografische ontwikkelingen en andere urbane uitdagingen op een houdbare wijze mogelijk maken. Hierbij is het van belang om reeds vanaf de ontwerptafel systemen zo vorm te geven dat ze nog onbekende toekomstige ontwikkelingen kunnen accommoderen.





Digitale Klankbordgroep
Technische Universiteit Eindhoven
Theo Arentze, Elphi Nelissen, Bauke de Vries
Ministerie van Veiligheid en Justitie
Pauline Arts
Universiteit Twente
Maya van den Berg
Leiden Universitair Medisch Centrum
Tobias Bonten
Gemeente Zaanstad
Ben-Willem Boswijk
Gemeente Rotterdam **Aat Brand,**
Hogeschool van Amsterdam
Lea den Broeder, Jeroen Kluck
Wageningen UR **Marleen Buizer, Gerben Mol, Joost Snels, Nina Waldhauer**
Windesheim **Willem Buunk**
Joop ten Dam
Hogeschool Rotterdam
Carolien Dieleman, Kees Machielse, Gert-Joost Peek, Peter van Waart
Technische Universiteit Delft
Marloes Dignum, Alexander Yarovoy
AMS Institute **Stephan van Dijk**
Hogeschool Van Hall Larenstein
Rik Eweg
Leiden Centre of Data Science
Jaap van den Herik
Technische Universiteit Delft
Frank van der Hoeven
Airbus Defense & Space
Reineke van der Kolk
Inholland **Olaf van Kooten, Guido Walraven**
Rathenau Instituut **Iris Korthagen**
Quantbase **Cint Kortmann**
Waag Society **Frank Kresin**
ASTRON **Gert Kruithof**
BOVAG **Rogier Kuin**
Universiteit Utrecht **Michiel de Lange**
Philips **Thomas Leenders**
Universiteit Leiden **Thed van Leeuwen, Judi Mesman**
Smart Data City **Hans Nouwens**
STW **Erwin Onderdijk**
Deltares **Henriette Otter**
CWI Amsterdam / Technische Universiteit Delft **Han La Poutre**
NWO **Jasper Roodenburg**
TNO **Dick Schmidt**
TKI Urban Energy
Liana Sjerps-Koomen
Van Staalduinen management en advies **Piet van Staalduinen**
Universitair Medisch Centrum Utrecht
Ilonca Vaartjes
NIOO-KNAW **Marcel Visser**
Universiteit van Amsterdam
Monique Volman
Haagse Hogeschool **Ruud van Wezel**
Waag Society **Sabine Wildevuur**

Vijf game–changers

De transitie naar een bestendig smart stad, die ook leefbaar zal zijn, stelt de wetenschap voor interessante nieuwe uitdagingen . Hoe kunnen we nieuwe perspectieven, samenwerkings-verbanden en paradigma's, concreet toegepast krijgen in de stad; wat werkt wel en wat niet? Hiertoe is een vijftal game-changers geformuleerd , (nieuwe) onderzoeksgebieden die zich tegelijk en in samenhang dienen te ontplooien om de kansen van de smart city te benutten, en mogelijke bezwaren vroegtijdig te onderkennen en te mitigeren.

Het is vooral de combinatie en samenhang van de vijf game-changers die maakt dat steden dynamische en leefbare Smart Cities worden. Hierbij wordt aangesloten bij typisch Nederlandse competenties, die ook internationaal sterk onderscheidend zijn. Het gaat dan binnen de context van deze NWA-route om effectieve vormen van samenwerken, polderen, zelfsturing, systeem denken, werken vanuit integraal perspectief en toegepaste technologie als antwoord op pragmatische vraagstellingen en urgenties. De goede internationale concurrentiepositie van Nederland wordt versterkt door haar wetenschappelijke positie, reputatie en competenties op het gebied van de voorgestelde vijf game-changing onderzoekskansen. Concentratie op deze onderwerpen zal voor Nederland kunnen leiden tot een verdere versterking van export van producten, diensten en kennis. Daarvan profiteert uiteindelijk dan iedereen: de Nederlander evenals de - buitenlandse - ontvanger van de 'Smart, liveable cities' producten en diensten.


adjustable translucent system to improve thermal comfort

PUBLIC

Annual ‘Newspapers’
Week van de Bouw 2015
GEVEL2016
InfraTech 2017
Bouwbeurs 2017
GEVEL2018

Besides various academic papers published by the individual research teams, 4TU.Bouw provided platforms for communicating results and potential to a larger professional audience within the built environment sector. Each year the results were published in a ‘newspaper’ style publication to be handed out to at both academic and non-academic events.

Also, on a yearly basis, the tangible results of the Lighthouse Projects in combination with the ‘newspapers’ and video interviews with the researchers were shown at building fairs aimed at the built environment sector ranging from designers and engineers to builders and end-users.

ANNUAL ‘NEWSPAPERS’

Each presenting the activities of 4TU.Bouw in the previous year. Aimed at a non-academic audience and offered next to academic papers and conference presentations on the initiative from individual research teams themselves.



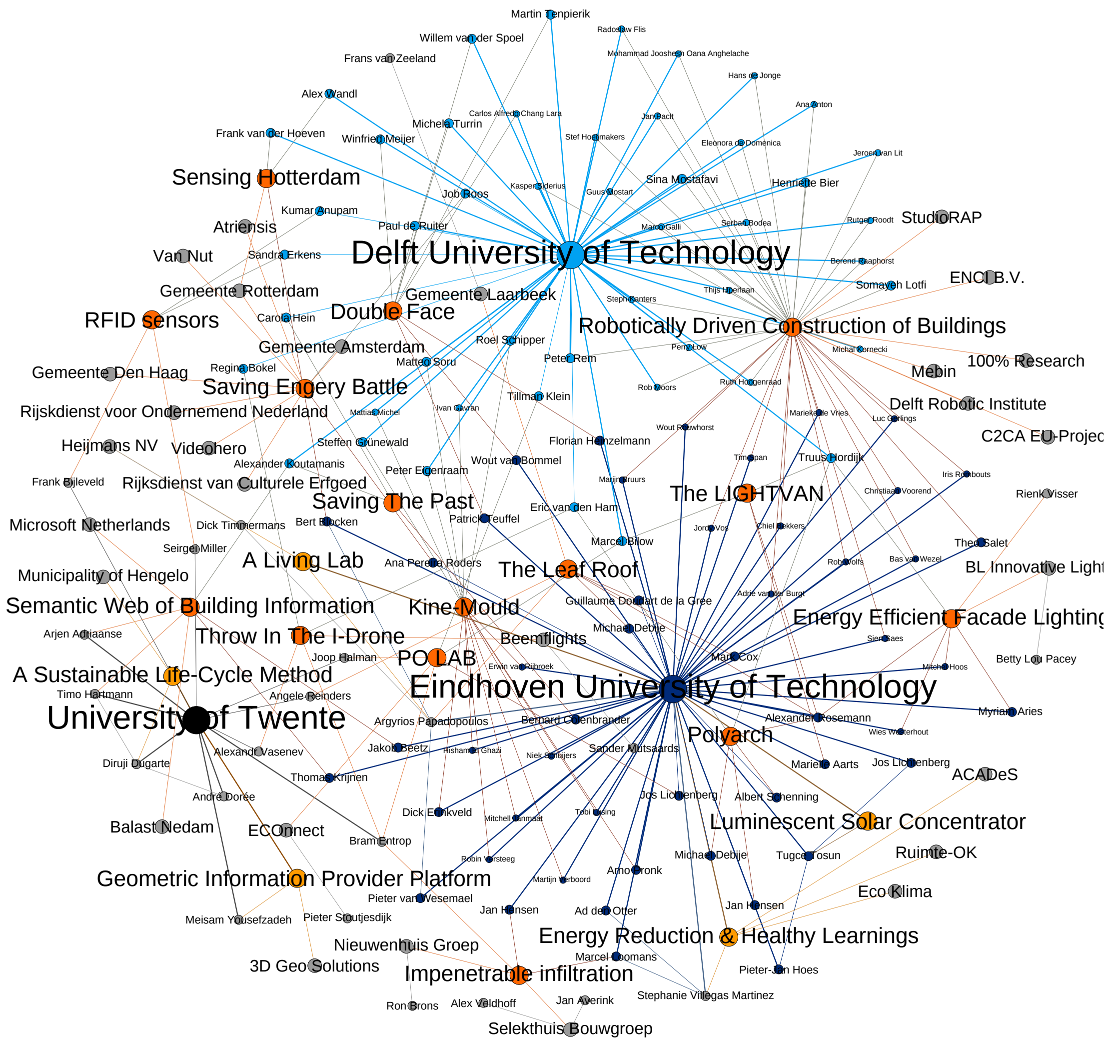



Editor
4TU.Bouw **Siebe Bakker**

with:
2014 bureaubakker
Anna Karina Janssen
2015 bureaubakker
Mariet Sauerwein
2016 bureaubakker **Elise Buiter**

3TU.Bouw
center of excellence for the built environment

Spring 2015



TUDelft Delft University of Technology | TU/e Technische Universiteit Eindhoven University of Technology | UNIVERSITY OF TWENTE.

3TU.Bouw

center of excellence for the built environment

7 Lighthouse Projects 2015

Lighthouse Projects aim at promoting and starting up imaginative research projects that are related to a current and urgent theme. The 'imaginative' nature of the research as well as the delivery of tangible results within a timeframe of one year distinguishes Lighthouse Projects from other funding schemes.

Update 4 Lighthouse Projects 2014

Four of the eight initial Lighthouse Projects have seen further development beyond the scope of the actual Lighthouse program: 'proof of concept' or 'proof of failure'. These developments range from extended research supported through other funding schemes, to commercial implementations.

Future Formats for Applied Research

In sessions with reasearchers, a venture capitalist, a crowdfunding specialist and university management, we investigated how formats for applied research need to adapt to a fast changing world in which 'startups' are the way to explore new ideas.

De Toekomst Wordt Gebouwd

Within the realm of the three technical universities – built environment – an inventory has been produced on relevant and urgent topics for developments in the coming years.

Real Additive Manufacturing

Additive Manufacturing (AM) is regarded as a very promising technique, but what are the important functions and characteristics of AM produced building components? Can additive manufactured elements already be implemented widely in the building industry, or should their performance be improved first?

5 Professional Doctorates in Engineering

PDEng is a two-year professional post-academic degree, where university graduates work in close collaboration with the industry on an urgent and industrially relevant topic. It offers a dedicated professional education programme to deliver young professionals that are able to bridge the gap between academia and the market.

15 Lighthouse Projects 2016

In 2016, fifteen new research proposals will start with a Lighthouse Project funding. All of them are closely related to one of the themes of 'De Toekomst Wordt Gebouwd'. They function as catalysts and results in the process of activating these urgent topics.

TUDelft Delft University of Technology | TU/e Technische Universiteit Eindhoven University of Technology | UNIVERSITY OF TWENTE.

4TU.Bouw 2016

center of excellence for the built environment

BIO BASED BRIDGE Eindhoven University of Technology: ir. Rijk Blok, Prof. Dr.-Ing. Patrick Teuffel – Delft University of Technology: ir. Joris Smits, ir. Rafail Gkaidatzis – Centre of Expertise Bio-Based Economy: ir. Willem Böttger, ir. Alwin Hoogendoorn – NPSP BV ir. Mark Lepelaar – Avans University of Applied Sciences – HZ University of Applied Sciences Built at SPARK location in Rosmalen CAST FORMWORK SYSTEM Technical University Delft: ir. Nadia Remmerswaal, Dr.-Ing. Marcel Bilow – Eindhoven University of Technology: dr. ir. Faas Moonen, ir. Rijk Blok – Jongeneel – Cementbouw – Van Gelder– GreenVillage – Riset 8 kota Indonesia CONVECTIVE CONCRETE Delft University of Technology: Dennis de Witte MSc., Prof.Dr.-Ing Ulrich Knaack – Eindhoven University of Technology: Marie de Klijn-Chevalerias MSc., ir. Roel Loonen, prof.dr.ir. Jan Hensen – G.tecz: Dr.-Ing Gregor Zimmermann DOUBLE CURVED CONCRETE PRINTING Delft University of Technology: dr. ir. Roel Schipper, Chris Borg Costanzi MSc. – Eindhoven University of Technology: dr. ir. Freek Bos, Zeeshan Ahmed MSc., Rob Wolfs MSc. FIBROUS SMART MATERIALS Delft University of Technology: dr. Nimish Biloria, ir. Javid Jooshesh – Eindhoven University of Technology – University of Twente – EURECAT – Atelier Robotic OPTIMISING 3D CONCRETE PRINTING Delft University of Technology, BEMNext lab: dr. ir. Jeroen Coenders, Maarten Mathot, Pascal Martens – Eindhoven University of Technology: dr. ir. Freek Bos, Rob Wolfs MSc. – White Lioness technologies: ir. Anke Rolvink, Puck Middelkoop MSc., dr. ir. Jeroen Coenders, Maarten Mathot PUBLIC SPACE FOR REFUGEES TU Eindhoven: prof. ir. Juliette Bekkering, ir. Sjef van Hoof, ir. Kornelia Dimitrova, ir. Eefje Hendriks – TU Delft: prof. ir. Michiel Riedijk, Rick Krosenbrink – Koninklijke Landmacht Commandant Peter van Sorgen RESTORATIVE GLASS Delft University of Technology: ir. Faidra Oikonomopoulou, ir. Telesilla Bristogianni, ir. Lida Barou, prof. ir. Rob van Hees, prof. ir. Rob Nijsse, dr. ir. Fred Veer – Eindhoven University of Technology: dr. ir. Henk Schellen, dr. ir. Jos van Schijndel – ABT – POESIA SMART SENSORS IN ASPHALT University of Twente: dr. ir. Seirgei Miller, mr. Joyraj Chakraborty, Jurian van der Vegt, Daan Brinkerink – Technical University of Delft: prof. dr. ir. Sandra Erkens, dr. Xueyan Liu, dr. Kumar Anupam – Boskalis BV: mr. Berwich Sluer, dr. ir. Mohamad Mohajeri – Technobis SOLAR BIKES: USER ACCEPTANCE Eindhoven University of Technology: dr. ir. Pauline van den Berg, prof. dr. Theo Arentze – University of Twente: prof. dr. ing. Karst Geurs BUILT SOCIETY SMART REALITY 4TU.Bouw: ir. Siebe Bakker, Prof.Dr.-Ing Ulrich Knaack, ir. Alexander Schmets – De Bouwcampus: Majorie Jans – Bouwend Nederland: Tom van Eck, Patrick Koimans, Joep Rats SOUND ABSORBING GLASS Delft University of Technology: ir. Anne Struiksma, dr. ir. Martin Tenpierik, ir. Ate Snijder, dr. ir. Fred Veer – Eindhoven University of Technology: ir. Bram Botterman, dr. ir. Maarten Hornikx – SiO2 glas: Hein van der Water – De Laurenskerk Rotterdam: Frank Migchielsen SPONG3D Delft University of Technology: ing. Maria Valentini Sarakinioti MSc., dr. MArch. Michela Turrin, MArch. M.Teeling, ir. Paul de Ruiter, Mark van Erk, dr. ir. arch. Martin Tenpierik, dr. ing. Thaleia Konstantinou MSc., Prof. Dr.-Ing. Ulrich Knaack – Eindhoven University of Technology: ir. Arno Pronk, Prof. Dr.-Ing. Patrick Teuffel, Arthur van Lier, Rens Vorstermans, Eline Dolkemade, Marie de Klijn MSc., ir. Roel Loonen, prof. dr. ir. Jan Hensen – KIWI Solutions: Dick Vlasblom SPYING THE UNDERGROUND University of Twente: Léon olde Scholtenhuis – Delft University of Technology: Dr.-Ing. Sisi Zlatanova, Xander den Duijn BSc., Anna-Maria Ntarladima MSc., Evangelos Theocharous MSc. – Municipality of Rotterdam – Recognize UNLEASH THE BUILDING BOTS Eindhoven Universty of Technology: Aant van der Zee – Delft University of Technology: Paul de Ruiter – TBI Kennislab: Hayo Meijs DE REUS VAN SCHIMMERT Eindhoven University of Technology: Konstantinos Tzanakakis, dr. Madeleine Gibescu, prof. dr. Ed Nijssen – De Reus van Schimmert: Nico Eurelings INDUSTRIAL SYMBIOSIS SOFTWARE Eindhoven Universty of Technology: Immanuel Geesing MSc., prof.dr.ir. Bauke de Vries – Stichting Bedrijventerrein Helmond: Frits Rutten TRANSITION TOWARDS DC MIRCO GRIDS Eindhoven University of Technology: Evi Ploumpidou, prof. dr. Sjoerd Romme, dr. Madeleine Gibescu – ABB BV: Arno Bronswijk – DC Flexhouse: Harry Stokman – Direct Current BV: Pepijn van Wiligenburg – NEBER: Wil Paulus – EPM BV SMART LIVABLE CITIES trekkersgroep: Teun Bokhoven – TS Energie, TKI Urban Energy, Tom van Eck – VNO-NCW / Bouwend Nederland, Patrick Koimans – Bouwend Nederland, Alexander Schmets – 4TU.Bouw, Liesbet van Zoonen – Erasmus Universiteit Rotterdam; voorbereidingsgroep: Carmen Aalbers – Wageningen UR, Martje van Ankeren – Nationaal Regieorgaan Praktijkgericht Onderzoek Sia, Luca Bertolini – Universiteit van Amsterdam, Colette Bos – Nationale Wetenschapsagenda, Geert-Jan Houben – Technische Universiteit Delft, Kees d'Huy – TNO, Marcus van Leeuwen – NWO, Vincent Smit – Vereniging Hogescholen / Haagse Hogeschool, Kamiel Spoelstra – NIOO-KNAW, Maarten van Steen – Universiteit Twente, Sandra Storm – Vereniging Hogescholen, Peter Paul van 't Veen – TNO, Jan Vreeburg – Wageningen UR; digitale klankbordgroep: Theo Arentze – Technische Universiteit Eindhoven, Pauline Arts – Ministerie van Veiligheid en Justitie, Maya van den Berg – Universiteit Twente, Tobias Bonten – Leiden Universitair Medisch Centrum, Ben-Willem Boswijk – Gemeente Zaanstad, Aat Brand – Gemeente Rotterdam, Lea den Broeder – Hogeschool van Amsterdam, Marleen Buizer – Wageningen UR, Willem Buunk – Windesheim, Jochem Cooiman – Gemeente Rotterdam, Joop ten Dam – Windesheim, Carolien Dieleman – Hogeschool Rotterdam, Marloes Dignum – Technische Universiteit Delft, Stephan van Dijk – AMS Institute, Rik Eweg – Hogeschool Van Hall Larenstein, Jaap van den Herik – Leiden Centre of Data Science, Frank van der Hoeven – Technische Universiteit Delft, Jeroen Kluck – Hogeschool van Amsterdam, Reineke van der Kolk – Airbus Defense & Space, Olaf van Kooten – Inholland, Iris Korthagen – Rathenau Instituut, Cint Kortmann – Quantbase, Frank Kresin – Waag Society, Gert Kruithof – ASTRON, Rogier Kuin – BOVAG, Michiel de Lange – Universiteit Utrecht, Thomas Leenders – Philips, Thed van Leeuwen – Universiteit Leiden, Kees Machielse – Hogeschool Rotterdam, Stan Majoor – Hogeschool van Amsterdam, Judi Mesman – Universiteit Leiden, Gerben Mol – Wageningen UR, Elphi Nelissen – Technische Universiteit Eindhoven, Hans Nouwens – Smart Data City, Erwin Onderdijk – STW, Henriette Otter – Deltares, Gert-Joost Peek – Hogeschool Rotterdam, Han La Poutre – CWI Amsterdam / Technische Universiteit Delft, Jasper Roodenburg – NWO, Dick Schmidt – TNO, Liana Sjerps-Koomen – TKI Urban Energy, Joost Snels – Wageningen UR, Piet van Staalduinen – Van Staalduinen management en advies, Ilonca Vaartjes – Universitair Medisch Centrum Utrecht, Marcel Visser – NIOO-KNAW, Monique Volman – Universiteit van Amsterdam, Bauke de Vries – Technische Universiteit Eindhoven, Peter van Waart – Hogeschool Rotterdam, Nina Waldhauer – Wageningen UR, Guido Walraven – INHolland, Ruud van Wezel – Haagse Hogeschool, Sabine Wildevuur – Waag Society, Alexander Yarovoy – Technische Universiteit Delft RESEARCH TO REALITY Eindhoven University of Technology Aant van der Zee, Delft Unversity of Technology Alex Wandl, 4TU.Bouw Alexander Schmets, Delft Unversity of Technology Ana Anton, 4TU.Bouw / University of Twente André Dorée, Delft University of Technology Anna Maria Ntarladima, Delft University of Technology Anne Struiksma, Delft University of Technology Anupam Kumar, Eindhoven University of Technology Arjan Habraken, Eindhoven University of Technology Arno Pronk, Delft University of Technology Bahman Ghiassi, Eindhoven University of Technology Bahman Hashemi, 4TU.Bouw / Eindhoven University of Technology Bauke de Vries, Delft University of Technology Bram Botterman, Carlien Roodink Consultancy Carlien Roodink, Delft University of Technology Carola Hein, Delft University of Technology Cas van der Zanden, Eindhoven University of Technology Chen Hung Chu, Delft University of Technology Chris Borg Costanzi, Delft University of Technology Christian Louter, SBRCURnet Cindy Vissering, Eindhoven University of Technology Davide Leonetti, University of Twente Denis Makarov, Eneco Dennis Ramondt, KIWI solutions Dick Vlasblom, Summum / Block Research Group, ETH Zürich Diederik Veenendaal, creative projects Dré Kampfraath, Delft University of Technology Edward Verbree, bureaubakker Elise Buiter, Eindhoven University of Technology Ella Braat, Delft University of Technology Enayat Hosseini Aria, 4TU.Bouw / Delft University of Technology Erik Schlangen, Delft University of Technology Erwin Jacobs, Delft University of Technology Faidra Oikonomopoulou, University of Twente Farid Vahdatikhaki, Eindhoven University of Technology Feixiong Liao, Delft University of Technology Foteini Setaki, 4TU.Bouw / Delft University of Technology Frank van der Hoeven, Eindhoven University of Technology Freek Bos, Eindhoven University of Technology Gamze Dane, Socrates Hans Jaap Moes, Kankan Tree Haydee Sheombar, Delft University of Technology Henriette Bier, University of Twente Hosseiny Alamday, Eindhoven University of Technology Ioulia Ossokina, Delft University of Technology Jan de Boer, University of Twente Janine Profijt, Delft University of Technology Javid Jooshesh, Eindhoven University of Technology Jia Guo, Delft University of Technology John Hanna, University of Twente Joyraj Chakraborty, Delft University of Technology Juan Azcarate, Delft University of Technology Koen Mulder, bureaubakker Kyra Galjee, University of Twente Léon olde Scholtenhuis, Delft University of Technology Lida Barou, Harmon-E / BredeStroomversnelling Maarten Hommelberg, Delft University of Technology Marcel Bilow, SBRCURnet Maria Hänsch, Eindhoven University of Technology Marie de Klijn, Delft University of Technology Mark van Erk, Delft University of Technology Martin Tenpierik, Delft University of Technology Michela Turrin, Eindhoven University of Technology Michiel Ritzen, Delft University of Technology Miktha Farid, Delft University of Technology Mladena Lukovic, Delft University of Technology Nadia Remmerswaal, Panos Sakkas, Eindhoven University of Technology Patrycja Pustelnik, Delft University of Technology Paul de Ruiter, Eindhoven University of Technology Pauline van den Berg, SBRCURnet Perica Savanovic, Delft University of Technology Piet van Staalduinen, Delft University of Technology Pirouz Nourian, University of Twente Priya Darshini Cheyyar Nageswaran, Delft University of Technology Qingpeng Li, Eindhoven University of Technology Qinyu Wang, Cementbouw Richard Giesen, Eindhoven University of Technology Rijk Blok, UNStudio Rob Henderson, Eindhoven University of Technology Roel Loonen, Delft University of Technology Roel Schipper, Eneco Ronald Root, 123DV architecten Rotterdam Samaneh Rezvani, Delft University of Technology Seyed Sedighi, 4TU.Bouw / bureaubakker Siebe Bakker, Delft University of Technology Sina Mostafavi, Eindhoven University of Technology Sjonnie Boonstra, Quby Stephen Galsworthy, Delft University of Technology Telesilla Bristogianni, Delft University of Technology Thaleia Konstantinou, Delft University of Technology Tommaso Venturini, Eindhoven University of Technology Torsten Schröder, Delft University of Technology Truus Hordijk, 4TU.Bouw / Delft University of Technology Ulrich Knaack, Delft University of Technology Vagos Theocharous, Delft University of Technology Valentini Sarakinioti, Eindhoven University of Technology Wen Jiang, Eindhoven University of Technology Wenshu Li, City of Rotterdam, Indonesian Dispora Network Wiwi Tjiook, VolkerWessels iCity Wouter Beelen, Eindhoven University of Technology Xiaoteng Pan INNOVATION EXPO Siebe Bakker, Marcel Bilow, Frank van der Hoeven, Nadia Remmerswaal, Michela Turrin CITY OF THINGS Siebe Bakker, Elise Buiter, Matthijs de Deckere, Kim Degen, Dré Kampfraath, Dennis Ramondt, Ronald Root, Mariet Sauerwein, Frans Schupp, Frank van der Hoeven, Nuno Varandas, Teun Verkerk REAL ADDITIVE MANUFACTURING Siebe Bakker, Elise Buiter, Marcel Bilow, Lenneart van Capelleveen, Jeroen Coenders, Chris Borg Costanzi, Ulrich Knaack, Paul de Ruiter, Valentini Sarakinioti, Roel Schipper, Holger Strauss, Michela Turrin, Dennis de Witte, Aant van der Zee 3D CONCRETE PRINTING FOR STRUCTURAL APPLICATIONS Eindhoven University of Technology Theo Salet, Delft University of Technology 65+ BEST NEIGHBOURHOOD CONCEPTS: HAPPY SENIOR LIVING Eindhoven University of Technology: Ioulia Ossokina, Delft University of Technology ADAPTIVE JOINTS WITH VARIABLE STIFFNESS Eindhoven University of Technology: Qinyu Wang, Delft University of Technology EXCASAFEZONE University of Twente: Léon olde Scholtenhuis, Delft University of Technology, Eindhoven University of Technology GEOPOLYMER CONCRETE BRIDGE Delft University of Technology: dr. G. Ye, Eindhoven University of Technology RE3 GLASS – A REDUCE/REUSE/RECYCLE STRATEGY Delft University of Technology: Telesilla Bristogianni, University of Twente RE-PRINTING ARCHITECTURAL HERITAGE Delft University of Technology: Carola Hein, Eindhoven University of Technology TERRA–INK: ADDITIVE EARTH MANUFACTURING FOR EMERGENCY ARCHITECTURE Delft University of Technology: Michela Turrin, Eindhoven University of Technology

Research and education collaboration between the Department of the Built Environment at Eindhoven University of Technology, faculty of Engineering Technology at University of Twente, the faculties of Architecture and Civil Engineering and Geosciences at Delft University of Technology and Wageningen University & Research.

4TU.Bouw

center of excellence for the built environment

TWO THOUSAND SEVENTEEN

eight innovative and collaborative Lighthouse Projects

three Post Doctorate in Engineering Projects

Lighthouse Projects Evaluation

City of Realities Workshop & Seminar

Infographic Workshops

WEEK VAN DE BOUW 2015

February 9 – 13, Utrecht

Organisation
4TU.Bouw **Siebe Bakker**,
bureaubakker **Anna Karina Janssen**

Lighthouse Projects
DoubleFace, Energy Efficient Facade Lighting, Impenetrable Infiltration, Kine-Mould, The LIGHTVAN, Robotically Driven Construction of Buildings, Semantic Web of Building Information & Sensing Hotterdam

PDEng Projects
Geometric Information Generator, Healthy Learning Environment, A Living Lab, Luminiscence Solar Concentrator & Sustainable Life-Cycle Method

Presentations
Marielle Aarts, Jacob Beetz, Marcel Bilow, Frank van der Hoeven, Sina Mostafavi, Roel Schipper & Michela Turrin

GEVEL 2016

January 27 – 29, Rotterdam

Organisation
4TU.Bouw **Siebe Bakker,**
bureaubakker **Mariet Sauerwein**

Lighthouse Projects
Architectures of the Black Golg, Leafroof, PD Lab, Polyarch, RFID Sensors, Saving Energy Battle & Throw in the I-Drone

PDEng Projects
Geometric Information Generator, Healthy Learning Environment, A Living Lab, Luminiscence Solar Concentrator & Sustainable Life-Cycle Method

Presentations
Zeeshan Ahmed, Marcel Bilow, Bram Entrop, Eric van den Ham, Seirgei Miller, Argyrios Papadopoulos, Ana Perreira Roders, Sandra K. Sánchez de la Garza, Lars van Vianen & Dennis de Witte

Real Additive Manufacturing Workshop
Aaron Bislip, Gaspard Estourgie, Arjan Klem, Bayu Prayudhi, Ali Sarmad, Dick Vlasblom & Dennis de Witte supported by KIWI Electronics









INFRATECH 2017

January 17 – 20, Rotterdam

Organisation
4TU.Bouw **Siebe Bakker**
bureaubakker **Elise Buiter**

Lighthouse Projects
Bio Based Bridge, CAST Formwork System, Convective Concrete, Double Curved 3D Concrete Printing, Fibrous Smart Materials, Optimising 3D Concrete Printing, Public Space for Refugees, Restorative Glass, Smart Sensors in Asphalt, Solar Bikes: User Acceptance, Sound Absorbing Glass, SPONG3D & Spying the Underground

PDEng Projects
De Reus van Schimmert, Industrial Symbiosis Software & Transition Towards Micro DC Grids

BOUWBEURS 2017

February 6 – 10, Utrecht

Organisation
4TU.Bouw **Siebe Bakker**
bureaubakker **Elise Buiter**

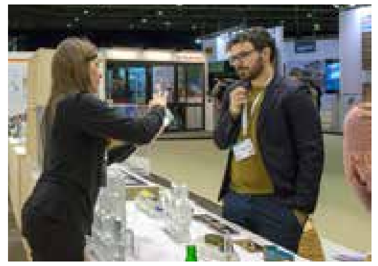
Lighthouse Projects
Bio Based Bridge, CAST Formwork System, Convective Concrete, Double Curved 3D Concrete Printing, Fibrous Smart Materials, Optimising 3D Concrete Printing, Public Space for Refugees, Restorative Glass, Smart Sensors in Asphalt, Solar Bikes: User Acceptance, Sound Absorbing Glass, SPONG3D & Spying the Underground

PDEng Projects
De Reus van Schimmert, Industrial Symbiosis Software,& Transition Towards Micro DC Grids

Presentations
Juliette Bekkering,
Pauline van den Berg,
Nimish Biloria, Telesilla Bristogianni,
Jeroen Coenders, Javid Jooshesh,
Seirgei Miller, Faidra Oikonomopoulou,
Nadia Remmerswaal, Bas Rongen,
Roel Schipper, Valentini Sarakinioti,
Anne Struiksma, Michela Turrin &
Dennis de Witte

GEVEL 2018

January 23 – 25, Rotterdam



Organisation
4TU.Bouw **Siebe Bakker**
bureaubakker
Kim Degen, Kyra Galjee

Lighthouse Projects
3D Concrete Printing for Structural Applications, Adaptive Joints with Variable Stiffness, ExcaSafeZone, Geocon Bridge, Happy Senior Living, Re3 Glass, Reprinting Architectural Heritage & TERRA-ink

PDEng Projects
Aerodynamic Optimization, Air Curtain Optimization & Sustainable Performance Optimization

Presentations
Freek Bos, Telesilla Bristogianni, Carola Hein, Mladena Lukovic, Faidra Oikonomopoulou, Dick Vlasblom

EVALUATION LIGHTHOUSE PROJECTS

Main Results
Interview Summary

At the start of 2017, just after completing three years of Lighthouse Projects, we evaluated the format. We specifically asked the researchers about their experiences with collaborating, the format in relation to the ones they already knew and the effects of participating in a Lighthouse Projects for their other research, future endeavours, professional networks, and so on.

Our goal of this evaluation was to gather information on how such a special research fund as the Lighthouse Projects has operated within the daily practice of the researchers and faculties. Did it fill a gap? Did it lead to unexpected results? Was there a necessity for this type of projects, offering opportunities for otherwise impossible research ambitions? And of course, to gain knowledge about possible follow-up initiatives.

LIGHTHOUSE PROJECTS EVALUATION

Basis

- Based on 46 respondents.
- All 30 Lighthouse Projects from 2014, 2015 and 2016 are represented.
- Most 2016 Lighthouse Projects do not yet show spin-off or impact, due to the delivery time of results end of 2016.

Main Findings Interviews

- Lighthouse Projects are highly valued as an additional type/format to other research funding.
- Positive assessment of collaboration regarding knowledge exchange and network building.
- Widespread industry collaboration in Lighthouse Projects.
- Lighthouse Projects valued as a successful (proven) base for applying for new and larger grants and industry involvement.
- Lighthouse Projects support and facilities are experienced as valuable additions to projects and personal skills.
- Nearly all projects have published independently from LHP program (scientific, press, exhibitions, etc.)
- In relation to projects within other funding systems a good score in terms of output volume, diversity, and unique concepts.
- The spin-off with/for industry and other funding grants seems limited. 2016 Lighthouse Projects are still in initial phases concerning spin-offs. 20 - 30% positive score is not bad in relation to 'high-risk' innovative R&D processes.

Main Findings Data Analysis

- 165 LHP applications (282 unique persons), 38 granted (including 2017 cycle – not part of the interview evaluation).
- 50% of researchers of granted project applied for a second cycle.
- 85% 2 TU's collaborating, 15% 3 TU's collaborating.

Considerations

- More support on project –, financial–, and communication management would improve the format.
- More clear and streamlined financial administrations in faculties may lead to more efficient processes
- Better explanation on the definition of tangible results in the call may attract a wider range of ideas.
- Budget availability also for "project hours" contracted staff is in 'high demand'.
- More 'after-care' in relation to follow-ups with/by industry (network, process, etc.) may help with better spin-off results.
- 38 Lighthouse Projects produce more results (collaborations, initiatives, ideas) in less time than for instance 5 Ph.D. projects with a comparable total budget
- Lighthouse Projects support organised by 4TU.Bouw (Infographics workshops) leads to similar support for other Ph.D. and PDEng projects (seen as valuable support / professional training).
- Communication actions (fairs and events) lead to collaborative pitching and presentations with interested (future) industry partners, and to industry's ambitions being presented for assessment by researchers for future collaboration.

FORMAT – LIGHTHOUSE PROJECT SETUP

Did you finish the project in one year?

Were you able to deliver a proof of concept/proof of failure?

How did you experience the one year length of the project?

Does the one year length of the project run better?

How did you experience the 4TU.Bouw support of the LHP?

Infographic

General support

Video interview

Newspaper article

Fairs

Were there any elements in the LHP format that had a negative effect?

What dit you value most about the LHP?

If you had the chance would you participate in another LHP?

FORMAT – VISIBILITY

Did the 4TU.Bouw organised exposure lead to a follow-up?

Did you publish your LHP elsewhere?

FORMAT – FUNDING

How do you think the following aspects of LHP operate in comparison to other funding formats?

No need for 3rd party funding

Time for call response

Two page call format

Call criteria

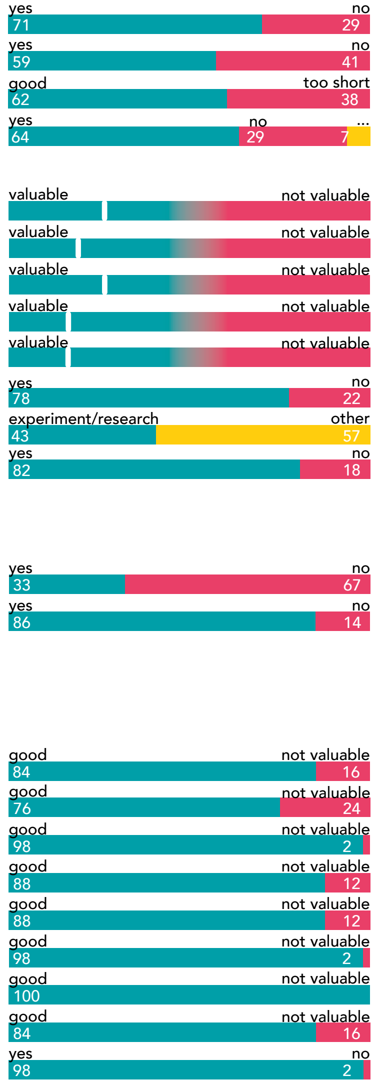
Required tangible result

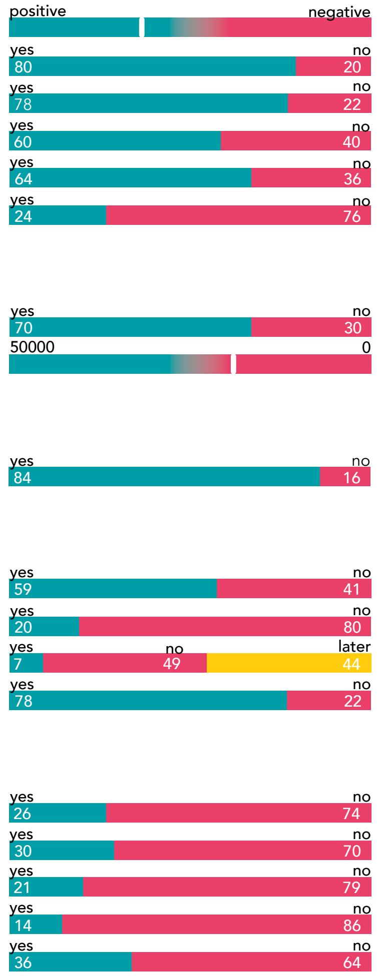
Required proof of concept

1 year time length

Relatively small grant

Do you think the LHP funding fills a gap in the range of available funds?





4TU COLLABORATION

How did you experience the collaboration with the other TU's?

Did the collaboration lead to more information exchange?

Do you think the LHP lead to different results, then a project without this collaboration would?

Did the collaboration lead to new connections/networks?

Did the 4TU collaborations continue after the LHP?

Did your connection with the 4TU.Bouw lead to any other opportunities?

COLLABORATION – INDUSTRY

Did you collaborate with the industry during the LHP?

Can you indicate the value of the industry involvement?

COLLABORATION TEACHING

Did students work on your LHP?

SPIN-OFFS – RESEARCH

Did the LHP lead to new research on this topic?

Did the LHP lead to new research?

Did you receive a new or larger grant for this research?

Was the LHP (will the LHP be) an imporatant factor for receiving a new or larger grant?

SPIN-OFFS – INDUSTRY

Did the industry involvement lead to more/new opportunities/collaborations?

Did your LHP lead to the creation of a product/service?

Was the result of the LHP picked-up by the industry?

Did your LHP result in a start-up potential?

Did you involve end-users in your research?

REMARKS

Is there anything you would like to share concerning the LHP?

surveyor
bureaubakker **Elise Buiter**


Re^{3} Glass

SPIN-OFF
Publications, Exhibitions and Grants

The Lighthouse Projects asked for a 'proof of concept' or 'proof of failure', plus a tangible result. Although these were the deliverables necessary to fulfill the requirements of the grant, most projects took the opportunity to create their own spin-off from their projects. 4TU.Bouw organised various events and publications catering to a wider, not specifically academic, audience. Most research teams also delivered academic papers, presented their work at conferences, gained other grants based on the work done in the Lighthouse Projects, and even won awards. The spin-off shows a broad academic and societal interest and relevance.

LIGHTHOUSE PROJECTS

This list is of the spin-off of the Lighthouse Projects known to the authors of this book and is not considered to be complete.

3D Concrete Printing for Structural Applications

- Bos, F.P., Ahmed, Z.Y., Jutinov, E.R. & Salet, T.A.M., *Experimental exploration of metal cable as reinforcement in 3D printed concrete*, Materials, 2017(10):1011134.
- Bos, F.P., Ahmed, Z.Y., Wolfs, R.J.M. & Salet, T.A.M., *3D printing concrete with reinforcement*. In M. Luković & D.A. Hordijk (Eds.), High Tech Concrete: where technology and engineering meet (pp. 2484-2493). Cham: Springer International Publishing.
- Domenico Asprone, Costantino Menna, Freek P. Bos, Theo A.M. Salet, Jaime Mata-Falcón, Walter Kaufmann, Rethinking reinforcement for digital fabrication with concrete (DFC), Cement and Concrete Research 112 (2018) 111–121.
- S. Chaves Figueiredo, C. Romero Rodriguez, Z.Y. Ahmed, D.H. Bos, Y. Xu, T.A.M. Salet, O. Çopuroğlu, F.P. Bos, and E. Schlangen, *Development of Printable Strain Hardening Cementitious Composite part I: Mix Design Development*, 1st International Conference on Concrete and Digital Fabrication Digital Concrete 2018 – Zurich, Switzerland, 10-12 September 2018, extended abstract.
- *Development of Printable Strain Hardening Cementitious Composite part II: Characterization of the Printed Composite* S. Chaves Figueiredo* (1), C. Romero Rodriguez (1), Z.Y. Ahmed (2), D.H. Bos (2), Y. Xu (1), T.A.M. Salet (2), O. Çopuroğlu (1), F.P. Bos (2), and E. Schlangen (1). 1st International Conference on Concrete and Digital Fabrication Digital Concrete 2018 – Zurich, Switzerland, 10-12 September 2018, extended abstract.
- F.P. Bos, E. Bosco, T.A.M. Salet, *Ductility of 3D Printed Concrete Reinforced with Short Straight Steel Fibers, Virtual and Physical Prototyping*. Status: Under review.
- Stefan Chaves Figueiredo, Claudia Romero Rodriguez, Zeeshan Y. Ahmed, D. H. Bos, Yading Xu, Theo M. Salet, Oguzhan Copuroglu, Erik Schlangen, Freek P. Bos, *Development of printable strain hardening cementitious composite - mix design development, Materials and Design*. Status: under review.

Adaptive Joints with Variable Stiffness

- Exposition Dutch Design Week 2018

Architectures of the Black Gold

- Carola Hein (2018) "*Oil Spaces: The Global Petroleumscape in the Rotterdam/The Hague area*" The Journal of Urban History. DOI: 10.1177/0096144217752460, http://journals.sagepub.com/doi full/10.1177/0096144217752460
- The Global Petroleumscape exhibition at Leiden University, 20.11.17-5.1.18
- The Global Petroleumscape exhibition at Groningen University, 18.10-19.11.17
- Project Leader, exhibition The Global Petroleumscape at TU Delft, 5.2017-6.2017
- Co-curator (with Mohamad Sedighi) of the exhibition Oliedam: Rotterdam in the oil era 1862-today at Museum Rotterdam, based on research by Carola Hein, 18.7.2016-15.1.2017
- *Oil Spaces*, Keynote Finnish Urban History Association Helsinki, 3-4 May,http://www.kaupunkitutkimuksenpaivat.net/ktp2018/keynotes-2018/carola-hein-oil-spaces-the-global-petroleumscape-in-the-rotterdam-the-hague-area/, 3-4.5.2018
- *Oil Spaces: The Global Petroleumscape in the Rotterdam/The Hague area*, ASCA UVA Amsterdam, 23.3.2018
- *Oil Spaces : Les espaces du pétrole dans l'Europe du Nord-Ouest*, Seminare du Groupe Transversale : Inventer Le Grand Paris, 15.2.2018
- *Oil Spaces: The Global Petroleumscape in the Rotterdam/The Hague area* Presentation in Roundtable: Beyond Instrumentality: Environmental Histories of Architecture, EAHN Tallinn, 16.6.18
- Session Organizer: The Global Petroleumscape: Spatializing the Impact of Physical and Financial Oil Flows and their Depiction and paper presentation "*The Palimpsestic Petroleumscape of the Dutch Randstad*" paper presentation, SACRPH Cleveland, 26-30.10.17
- (with Paolo de Martino) "*Architecture and Urbanism Beyond Oil: Designing the transition in Rotterdam and Dunkirk*" conference "Beyond Oil" Spacelab, Bergen, 25-28.10.17

Bio Based Bridge

- Exposition Dutch Design Week 2016
- E52 (online), 24-10-2016, *TU Eindhoven Builds the worlds first biobridge*
- Stedebouw & Architectuur (online), 24-10-2016, *'s Werelds eerste brug van biocomposiet*

- Nationale Onderwijsgids, 24-10-2016, *ROC's en Universiteiten maken 's werelds eerste biobrug op campus TU Eindhoven*
- Duurzaamgeproduceerd.nl (online), 24-10-2016, *Brug van biocomposiet op campus TU Eindhoven*
- MVO Nederland (online), 24-10-2016, *'s Werelds eerste brug van biocomposiet op campus TU Eindhoven*
- PetroChem (online), 24-10-2016, *Brug van BioComposiet op campus TU Eindhoven*
- Radio 1 (radio), 25-10-2016, Radio 1 Journaal
- Radio 2 (radio), 25-10-2016, Headlines
- Omroep Brabant radio (radio), 25-10-2016, Nieuws
- Studio 040 (radio), 25-10-2016, Headlines
- Studio 040 (online), 25-10-2016, *Eerste biocomposietbrug ter wereld op zijn plek gezet*
- Dichterbij.nl (online), 25-10-2016, '*s Werelds eerste brug van biocomposiet op campus TU Eindhoven*
- Duurzaam Bedrijfsleven (online), 25-10-2016, *TU Eindhoven test duurzaam biocomposiet voor bruggen*
- NOS (online), 25-10-2016, *Eindhoven krijgt een 'hennepbrug'*
- Eindhovens Dagblad (online), 25-10-2016
- Newsmonkey (online), 25-10-2016, *Nederlandse studenten bouwen allereerste hennepbrug in Eindhoven*
- EngineersOnline (online), 25-10-2016, *'s Werelds eerste brug van biocomposiet op campus TU Eindhoven*
- Univers (online), 25-10-2016, *Studenten bouwen brug van hennep*
- Omroep Brabant (radio), 25-10-2016, Nieuws
- Omroep Braband (online), 25-10-2016, *Voetgangersbrug van hennep in Eindhoven, geen eerbetoon aan overleden zanger Armand*
- De Telegraaf, 25-10-2016, *Brug nu ook van bio*
- De Telegraaf (online), 25-10-2016, *Eindhoven maakt brug van hennep en vlas*
- De Ingenieur (online), 25-10-2016, *TU Eindhoven heft een brug van biocomposiet*
- Link Magazine (online), 25-10-2016, *TU Eindhoven launching customer van 's werelds eerste brug van biocomposiet.*
- New Atlas (online), 25-10-2016, *Sensor-filled biobridge opening to foot traffic in the Netherlands*
- NLTimes (online), 25-10-2016, *World's first bio-composite bridge built in Eindhoven*
- Eindhovens Dagblad, 26-10-2016, *Geen grammetje thc in 'wietbrug'*
- Brabants Dagblad, 26-10-2016, *Er zit geen gram thc in de 'wietbrug'*
- Cobouw (online), 26-10-2016, *Brug van biocomposiet in Eindhoven*
- Engineeringnet (online), 26-10-2016, *'s Werelds eerste brug van biocomposiet op campus TU Eindhoven*
- Kunststof & Rubber (online), 26-10-2016, *Grootste object van biocomposiet ligt over Dommel bij TU/e*
- Digital Trends (online), 26-10-2016, *Sensor-packed sustainable biobridge will open in the Netherlands on Thursday*
- BNR (radio), 27-10-2016, BNR Ochtendspits
- Reformatorisch Dagblad, 27-10-2016, *Eindhoven opent brug van biocomposieten*
- KIJK (online), 27-10-2016, *Brug van hennep opent in Eindhoven*
- De Architect (online), 27-10-2016, *Bio-based brug in Eindhoven*
- BNR (radio), 31-10-2016, BNR Eyeopeners
- VRT (radio), 02-11-2016, Het Journaal 19.00 uur
- Technisch Weekblad (online), 03-11-2016, *Eerste 'biobrug' in Eindhoven*
- Technisch Weekblad, 04-11-2016, *Eerste 'biobrug' in Eindhoven*
- Reuters (online video), 18-01-2017, *Dutch "biobridge" made from hemp and flax fibres*
- Smits, Joris, Gkaidatzis, Rafail, Blok, Rijk & Teuffel, Patrick M. (2016). *Bio-based composite pedestrian bridge.Part 1: design and optimization*. In M. Ohsaki, K. Kawaguchi & T. Takeuchi (Eds.), Proceedings of the IASS Annual Symposium 2016 "Spatial Structures in the 21st Century", 26–30 September, 2016, Tokyo, Japan (pp.1-10).
- Lepelaar, Mark, Hoogendoorn, Alwin, Blok, Rijk & Teuffel, Patrick (2016). *Bio-based composite pedestrian bridge. Part 2: materials and production process.* In M. Ohsaki, K. Kawaguchi & T. Takeuchi (Eds.), Proceedings of the IASS Annual Symposium 2016 "Spatial Structures in the 21st Century", 26–30 September, 2016, Tokyo, Japan (pp. 1-10).
- (2017) Proceedings of the IASS Annual Symposium 2017 (to be published
- (2017) Footbridge2017, (to be published)
- Lecture at Bauwtechnik-tag
- Lectures at Elemente-material 2017
- Lectures at textile-Architecture

CAST Formwork System

- Prototype (2017) cast at Green Village
- Algemeen Dagblad Haagse Courant, 27-12-2016, "*Vinding maakt woningen aardbevingsbestendig*"
- TedX Bimhuis, 02-03-2016, "*To strive for Change: A Bottum-Up Approach"*

Convective Concrete

- Dennis de Witte, Marie L. de Klijn-Chevalerias, Roel C.G.M. Loonen, Jan L.M. Hensen, Ulrich Knaack, Gregor Zimmermann (2017), *Convective Concrete – Additive Manufacturing to facilitate activation of thermal mass*, journal of facade design & engineering volume 5 / number 1. doi 10.7480/jfde.2017.1.1430
- de Klijn-Chevalerias, M.L., Loonen R.C.G.M., Zarzycka, A., de Witte, D., Sarakinioti, M.V. and Hensen, J.L.M. (2017) *Assisting the development of innovative responsive façade elements using building performance simulation*. In Proceedings of SimAUD2017, 22-24 May, Toronto, Canada.
- de Witte, D., de Klijn, M.L., Loonen, R.C.G.M., Hensen, J.L.M., Knaack, U. & Zimmermann, G. (2017). *Convective Concrete: Additive Manufacturing to facilitate activation of thermal mass*. Journal of Facade Design and Engineering, 5(1), 107-117.
- de Witte, D., de Klijn, M.L., Loonen, R.C.G.M., Hensen, J.L.M., Knaack, U. & Zimmermann, G. (2017). *Convective Concrete: additive manufacturing to facilitate activation of thermal mass*. In Th. Auer, J. Schneider & U. Knaack (Eds.), POWERSKIN Conference (pp. 319-319). TU Delft Open.
- de Witte, D., Bilow, M., van Loonen, R., de Klijn, M.L., Knaack, U., Hensen, J., *Convective Concrete*. In imagine 10 - RAPIDS 2.0. ISBN 9789462082939

Double Curved 3D Concrete Printing

- Borg Costanzi, C., Knaack, U., *Freeform Concrete Printing: a Hybrid System for Fabricating Complex Concrete Geometries*. In imagine 10 - RAPIDS 2.0. ISBN 9789462082939
- journal publication Elsevier Automation in Construction: *3D Printing Concrete on temporary surfaces: The design and fabrication of a concrete shell structure*, C.Borg Costanzi, Z.Y.Ahmed, H.R.Schipper, F.P.Bos, U.Knaack, R.J.M.Wolfs, Automation in Construction: https://authors.elsevier.com/c/1XSQi3IhXMbm2y
- RILEM State-of-the-Art (STAR) report on Digital Fabrication with Cement-based Materials: case-study in chapter 2 *Digital Fabrication In The Concrete Industry* (to be published) will discuss the 4TU.Lighthouse project

- conference publication: Borg Costanzi, C.; Ahmed, Z.; Schipper, H.; Bos, F.; Knaack, U. & Wolfs, R. in Bögle, A. & Grohmann, M. (Eds.) ***3D Printing Concrete on Temporary Surfaces: The design and Fabrication of a Concrete Shell Structure***, Proceedings of the IASS Annual Symposium, 2017
- image of our 4TU.Lighthouse prototype in Elsevier article: Article: Buswell, R. A.; Leal de Silva, W. R.; Jones, S. Z. & Dirrenberger, J., 3D printing using concrete extrusion: A roadmap for research, Cement and Concrete Research, 2018, 112, 37-49
- prototype image shown during keynote presentation at Digital Concrete Zürich 2018, First RILEM International Conference on Concrete and Digital Fabrication

DoubleFace

- Double Face 2.0, granted research funding in the NWO Research Through Design program, 2015.
- Exhibition La Biennale Architettura 2018 Venice
- Research Exhibition 2017, June 9-10, 2017, Theater de Veste, Delft
- TU Delft Research Exhibition 2017, June 6-8, 2017, TU Delft, Delft
- Cobouw (online), 03-02-2015, ***Gevelelement bespaart energie***
- Tenfelde, A. (2016), ***Binnenmuur houdt huis warm***, Infographic, Impact 2 (3): 12-13.
- Tenpierik, M., M. Turrin, Y. Wattez, T. Cosmatu and S. Tsafou (2018), "***Double Face 2.0: A lightweight translucent adaptable Trombe wall***", Spool 5 (2: Expo #1), online <https://doi.org/10.7480/spool.2018.2.2090>.
- Wattez, Y., T. Cosmatu, M. Tenpierik, M. Turrin and F. Heinzelmann (2017), "***Renewed Trombe wall passively reduces energy consumption***", In: L. Brotas, S. Roaf and F. Nicol (eds.), Proceedings of the 33rd international conference on passive and low energy architecture – Design to thrive, Volume III, PLEA/Heriot Watt University/NCEUB, Edinburgh, July 2-5, pp. 902-909.
- Cosmatu, T., Y. Wattez, M. Turrin and M. Tenpierik (2017), "***Integrating technical performances within design exploration. The case of an innovative Trombe wall***", In: M. Turrin et al. (eds.), Proceedings of the Symposium on Simulation for Architecture and Urban Design, SCS / University of Toronto, Toronto, May 22-24, pp. 101-104.
- Tenpierik, M. (2017), "Double Face 2.0 – ***A Lightweight Translucent Adaptable Trombe Wall***", Rumoer 66: 6-11.
- Turrin, M., M. Tenpierik, P. de Ruiter, W. van der Spoel, C. Chang Lara, F. Heinzelmann, P. Teuffel, W. van Bommel (2014), "***DoubleFace: Adjustable translucent system to improve thermal comfort***", Spool 1 (2): 5-9, online <http://dx.doi.org/10.7480/spool.2014.2.929>.
- invited discussion panelist, research through design, Drive Festival, Dutch Design Week, Eindhoven, October 25, 2018.
- invited presentation, Double Face 2.0, Drive Festival, Dutch Design Week, Eindhoven, October 26, 2017.
- invited presentation, Double Face 2.0, Drive Festival, Dutch Design Week, Eindhoven, October 27, 2016.

Happy Senior Living

- Symposium Happy Senior Living, TU/e, 2018
- Ossokina, I., et al., ***Best living concepts for elderly homeowners***, Netspar, 2018

Impenetrable Infiltration

- A.G. (Bram) Entrop M.G.L.C. Loomans , Jan Hensen (2015), ***Luchtdoorlatendheid van woningen (deel 1)***, TVVL Magazine, No 6
- A. .G. (Bram) Entrop M.G.L.C. Loomans , Jan Hensen (2015), ***Luchtdoorlatendheid van woningen (deel 2)***, TVVL Magazine, No 10
- C.N. Bramiana, A.G. Entrop, J.I.M. Halman (2016), ***Relationships between building characteristics and airtightness of Dutch dwellings***, SBE16 Tallinn and Helsinki Conference

Kine-Mould

- Schipper, H.R., Eigenraam, P., Grünewald, S., Soru, M., Nap, P., Van Overveld, B., Vermeulen, J. (2015). ***Kine-Mould: Manufacturing technology for curved architectural elements in concrete***, Proceedings of the International Society Of Flexible Formwork (ISOFF) Symposium
- Prototype object shown during exposition with IASS Conference Future Visions in Amsterdam, 2015
- journal publication: Hawkins, W. J.; Herrmann, M.; Ibell, T. J.; Kromoser, B.; Michaelski, A.; Orr, J. J.; Pedreschi, R.; Pronk, A.; Schipper, H. R.; Shepherd, P.; Veenendaal, D.; Wansdronk, R. & West, M. H., ***Flexible formwork technologies: A state of the art review***, Structural Concrete, Ernst & Sohn, 2016 , 911-935
- Schipper, H. & Eigenraam, P., Maakbaarheid - Flexibele herbruikbare mal, 2016, http://www.tektoniek.nl/maakbaarheid/flexibele-herbruikbare-mal
- patent application: Eigenraam, P. & Schipper, H. R., Patent NL2011770C: Apparatus for forming a curved panel from a flat panel, 2015
- Grünewald, S.; Schipper, H. & Hordijk, D. in Fehling, E.; Middendorf, B. & Thiemicke, J. (Eds.), ***Double-curved panels produced in a flexible mould with self-compacting fibre-reinforced concrete***, Proceedings of HiPerMat 2016 - 4th Internation Symposium on Ultra-High Performance Concrete and High Performance Construction Materials, kassel university press GmbH, Kassel, 2016, 163-164
- Tissink, A., ***Geweven verenstaal oplossing voor flexibele mal***, Cobouw, 2015, February 18 nr. 32 , 6-7

Optimising 3D Concrete Printing

- Bouw en Aanbesteding Beton Special, 24-08-2016, '***Materiaal geprogrammeerd: een revolutie in aantocht***'
- Rumoer, Periodiek Voor De Bouwtechnologie, (2016) '***Programmable Structures and Materials: How 3D printing and new software can revolutionise the AEC industry***'
- Martens, P., Mathot, M., Bos, F.P. & Coenders, J., ***Optimising 3D printed concrete structures using topology optimisation***. In M. Luković & D.A. Hordijk (Eds.), High Tech Concrete: where technology and engineering meet (pp. 301-309). Cham: Springer International.
- Martens, P.A., Mathot, M., Coenders, J.L., Bos, F.P. & Rots, J.G., ***Optimising 3D printed concrete structures using topology optimisation***, Interfaces: Architecture. Engineering.Science : Proceedings of the IASS Annual Symposium 2017, 25-28 September 2017, Hamburg, Germany (pp. 1-9)
- Artikel U-Base
- Nominated for InfraTech 2017 innovatieprijs, Poster en filmpje.
- Organisation of Seminar Bouw4.0, 31-05-2017

PD Lab

- Opening PD lab, TU Delft, 12-05-2017
- Exposition Biennale Architettura 2018 Venice
- Stoutjesdijk Pieter et al. *Product Development Lab (PD Test Lab)*. SPOOL, [S.l.], v.5, n. 2, apr. 2018
- CINARK Symposium: *The Detail Is Dead – Long Live The Detail*, Copenhagen, 2017

Public Space for Refugees

- Exposition Dutch Design Week 2016

Re3 Glass

- Nominated for the New Material Award 2018, by Het Nieuwe Instituut + Fonds Kwadraat + Stichting Doen
- Exposition Biennale Architettura 24 May- 25 November 2018, Venice
- Exposition Dutch Design Week 20-28 October 2018, Eindhoven
- Exposition Glasstec, 23-26 October 2018, Dusseldorf
- Exposition Droog, 3 November-2 December 2018, Amsterdam
- Exposition WAF, 28-30 November 2018, Amsterdam
- Exposition Salone del Mobile, 9-14 April 2019, Milan (to be exhibited
- Exposition Techniek in de Etalage, 20 April to 30 June, at the city centre of Delft within the City of Technology initiative.
- Exposition 25 selected projects Dig-it Research, 9-10 June 2017, Theater de Veste, Delft
- Exposition Dig-it TU Delft Research 6-8 June 2017, Delft
- F. Oikonomopoulou, T. Bristogianni, L. Barou, F. Veer, R. Nijsse, 2018. *The potential of cast glass in structural applications. Lessons learned from large-scale castings and state-of-the art load-bearing cast glass in architecture*. Journal of Building Engineering.
- F. Oikonomopoulou, T. Bristogianni, L. Barou, E. Jacobs, G. Frigo, F. Veer, R. Nijsse, 2018. *Interlocking cast glass components, exploring a demountable dry-assembly structural glass system*. Heron Journal.
- F. Oikonomopoulou, T. Bristogianni, L. Barou, E. Jacobs, G. Frigo, F. Veer, R. Nijsse, 2018. *A novel, demountable structural glass system out of dry-assembly, interlocking cast glass components*. Challenging Glass 6 Conference Proceedings, Delft.
- T. Bristogianni, F. Oikonomopoulou, C. Justino de Lima, F. Veer, R. Nijsse, 2018. *Cast Glass Components out of Recycled Glass: Potential and Limitations of Upgrading Waste to Load-bearing structures*. Challenging Glass 6 Conference Proceedings, Delft.
- T. Bristogianni, F. Oikonomopoulou, C. Justino de Lima, F. Veer, R. Nijsse, 2018. *Structural cast glass components manufactured from waste glass: Diverting everyday discarded glass from the landfill to the building industry*. Heron Journal
- F. Oikonomopoulou, *A novel design philosophy for glass load-bearing structures that facilitate glass recycling*. Oral presentation at ICG Annual Meeting 2018, Yokohama, Japan.
- T. Bristogianni, *Structural cast glass components out of glass waste: Diverting everyday discarded glass from the landfill to the building industry*. Oral presentation at ICG Annual Meeting 2018, Yokohama, Japan.
- F. Oikonomopoulou & T. Bristogianni, *The structural potential of cast glass*. Lecture at SIU, Illinois, USA.
- F. Oikonomopoulou & T. Bristogianni ,*The structural potential of cast glass*. Lecture at SHoP Architects, New York, USA.
- F. Oikonomopoulou & T. Bristogianni , *The structural potential of cast glass*. Lecture at Penn University, Pennsylvania, USA.
- F. Oikonomopoulou & T. Bristogianni , *The structural potential of cast glass*. Lecture at James Carpenter Design Associates, New York, USA.
- F. Oikonomopoulou & T. Bristogianni, R*e3 Glass: A novel design philosophy for loadbearing structures out of waste glass*, Dutch Design Week 2018 Walk& Talk, Eindhoven
- F. Oikonomopoulou & T. Bristogianni , *Re3 Glass, New Innovative and sustainable roads for building with glass*. Innovatieve Materialen

Reprinting Architectural Heritage

- Various exhibitions

Restorative Glass

- Granted a LHP 2017, '*Re3 Glass, a reduce/reuse/recycle strategy*'
- Oral presentation: "*Restoring and structurally reinforcing historic monuments by glass*", speaker: F. Oikonomopoulou, SEMC 2016 conference, Cape Town (SA)
- Oral presentation: "*Transparent restoration*", speaker: L.Barou, IABSE 2017 conference, Bath (UK)
- Oral presentation: "*Transparent restoration*", speaker: L.Barou (, WTA-NL-VL Studiedag 2017, Roosendaal (NL)
- F.Oikonomopoulou, T.Bristogianni, F.A.Veer, R.Nijsse, 2018. T*he construction of the Crystal Houses façade: challenges and innovations*. Glass Structures & Engineering Journal, 2017, DOI 10.1007/s40940-017-0039-4.
- L. Barou, F. Oikonomopoulou, Tt. Bristogianni, F. Veer, R. Nijsse, 2018. *Structural glass: A new remedial tool for the consolidation of historic structures*. Heron Journal.

RFID Sensors

- Sjon van Dijk, Seirgei Miller, Marco Oosterveld, *RFID sensoren en asphalt… een goede match?*, Infradagen 2016
- Cobouw 20, 1-02-2016, *Sensor houdt toestand van wegdek bij*
- Sergei Miller, 01-07-2016, *Will smart cars drive on smart roads? – RFID sensors and asphalt*, Chinese European Workshop (CEW) presentation
- Sjon van Dijk, Seirgei Miller, Marco Oosterveld, *RFID sensoren voor asfaltmetingen*, CROW Infradagen 2016

Robotically Driven Construction of Buildings

- Exhibitor Dutch Design Week 2015
- Delta, 11-01-2016, *Hyperbody: Making smart robotic processes to improve our built environment*
- Bier, H. *Robotic Building - Customized Design to Robotic Production for Additive Manufacturing*. In imagine 10 - RAPIDS 2.0. ISBN 9789462082939

Sensing Hotterdam

- van der Hoeven, F., & Wandl, A. (2017). *Hotterdam: mapping the Rotterdam urban heat island*. project baikal, 12(45), 138-145. doi:http://dx.doi.org/10.7480/projectbaikal.45.906
- van der Hoeven, F., & Wandl, A. (2015), *Hotterdam: Hoe ruimte Rotterdam warmer maakt, hoe dat van invloed is op de gezondheid van de inwoners, en wat er aan te doen is*. ISBN-13: 978-9461865069

- Wandl, A. & van der Hoeven, F. (2015). ***Hotterdam: Urban heat in Rotterdam and health effects***. TU Delft. Dataset. Available at http://dx.doi.org/10.4121/uuid:be41b523-1f1a-4f46-82d1-09c2c24f357b
- van der Hoeven, F., Wandl, A., Demir, B., Dikmans, S., Hagoort, J., Moretto, M., ... & Yakovleva, N. (2014). ***Sensing Hotterdam: Crowd sensing the Rotterdam urban heat island***. SPOOL, 1(2), 43-58.
- van der Hoeven, F., & Wandl, A. (2018). ***Hotterdam: Mapping the social, morphological, and land-use dimensions of the Rotterdam urban heat island***. Urbani Izziv, 29(1).

Smart Monitoring of Bridge Performance

- Eliz-Mari Lourens, Dominik Fallais (2017) ***General conditions for full-field response monitoring in structural systems driven by a set of identified equivalent forces, Experimental Vibration Analysis for Civil Engineering Structures*** July 12-14.

Smart Sensor System

- Sandra Erkens, Seirgei Miller, Sjon van Dijk, ***Will smart cars drive on smart roads? Sensor systems in asphalt concrete***, TRA (to be published)

Solar Bikes: User Acceptance

- Van den Berg, P., Vinken, S., Geurs, K. and Arentze, T. (2017) ***Solar bike acceptance: mode choice behavior***. Paper presented at the Velo-city Scientists for Cycling Colloquium, Nijmegen, June 12, 15 pp.
- Van den Berg, P., Vinken, S., Geurs, K. and Arentze, T. (2018) ***Stated choice model of transportation modes including solar bike***, JTLU, Vol 11, No 1

SPONG3D

- de Klijn-Chevalerias, M.L., Loonen R.C.G.M., Zarzycka, A., de Witte, D., Sarakinioti, M.V. and Hensen, J.L.M. (2017) ***Assisting the development of innovative responsive façade elements using building performance simulation***. In Proceedings of SimAUD2017, 22-24 May, Toronto, Canada
- Konstantinou, T. et al., (2017) ***SPONG3D: Developing an integrated 3D printed façade for active control in complex geometries***. Abstract submitted for NextFacades conference. http://nextfacades.at/
- Expositie Dutch Design Week 2016 – Mind the Step: http://www.mindthestep.nl/spong3d.html
- Elsevier 3D Printing Grand Challenge http://www.materialstoday.com/elsevier-3d-printing-grand-challenge/.
- Sarakinioti, M.V., Knaack, U., Turrin, M., Tenpierik, M., ***The “Soft” Spongy Skin***. In imagine 10 - RAPIDS 2.0. ISBN 9789462082939

Spying the Underground

- L.L. olde Scholtenhuis1, S. Zlatanova2, and X. den Duijn, (2017) ***3D approach for representing uncertainties of underground utility data***, IWCCE: International Workshop on Computing in Civil Engineering 2017. (to be published)
- Cobouw, 2016-12, ***Ondergrondse leidingen lokaliseren met 3D-tool***
- Leon L. olde Scholtenhuis, Xander den Duijn, Sisi Zlatanovam (2018) ***Representing geographical uncertainties of utility location data in 3D***, Automation in Construction Volume 96, 2018
- Olde Scholtenhuis LL, & Vahdatikhaki F. 2018. ***Toepassingen van Augmented en Virtual Reality in de GWW***, in: CROW Infradagen 2018, Papendal
- Workshop Augmented Reality voor de ondergrond, in ZoARG Symposium oktober 2017

TERRA-ink

- Exposition Materia 2018 – Rotterdam Ahoy
- Exposition Innovative materials 2018 – Veldhoven, Netherlands
- Part of the course and exhibition for the ‘Science Fair 2018: advanced prototyping’ by J. Verlinden, T.Venturini – TU Delft
- Part of the course ‘Design and construction of innovative structural objects’, by A.Pronk – TU Eindhoven
- Invited presentation at RILEM symposium 2018 – TU Delft
- Article in ‘Rumoer journal #67: Native resources’, February 2018 – T.Venturini, M.Turrin, F.Setaki
- Article in ‘Innovative materials 2018’

PEOPLE

University Staff and Students – 4TU.Bouw
Industry and Institutions
Organisation

Over the four-year period from 2014 to 2017, around 350 researchers and students from the faculties affiliated with 4TU.bouw worked with at least 300 experts from other faculties, industries, market parties and governments on a range of collaborative research projects, match-making events, and investigative workshops and conferences.

We tried to list all who have participated and contributed, however, some may have been out of our sights. We do like to thank everyone involved with the 4TU.Bouw activities, not only by supporting our ambitions but by making them happen and taking the results beyond the scope of 4TU.Bouw.

UNIVERSITY STAFF & STUDENTS - 4TU.BOUW

ir. **Carmen Aalbers** – Wageningen University and Research: Smart Liveable Cities
ir. **Mariëlle Aarts** – Eindhoven University of Technology: LHP2014 The LIGHTVAN, Future Formats for Applied Research
prof.dr.ir. **Arjen Adriaanse** – University of Twente: LHP2014 Semantic Web of Building Information
Zeeshan Ahmed MSc. – Eindhoven University of Technology: LHP2016 Double Curved Concrete Printing, LHP2017 3D Concrete Printing for Structural Applications, Real Additive Manufacturing: 3D Concrete Printing
Hosseiny Alamday – Delft University of Technology: Research to Reality – Bootcamp
ir. **Claudio Alanis Ruiz** – Eindhoven University of Technology: PDENG Air Curtain Optimization
Zainab Aldin MSc. – Delft University of Technology: LHP2017 GeoCon Bridge
Carlos Alfredo Chang Lara MSc. – Delft University of Technology: LHP2014 DoubleFace
Zahara Allah Bukhsh MSc. – University of Twente: Infographic Workshop Facilitating Decision-making Process of Railway Maintenance and Management
Lida Aminian M.Arch. – Eindhoven University of Technology: City of Realities
ir. **Ana Anton** – Delft University of Technology: LHP2014 Robotically Driven Construction of Buildings, Research to Reality
dr. **Kumar Anupam** – Delft University of Technology: LHP2016 Smart Sensors in Asphalt
prof.dr. **Theo Arentze** – Eindhoven University of Technology: LHP2016 Solar Bikes: User Acceptance, LHP2017 Happy Senior Living, Smart Liveable Cities
dr. **Myriam Aries** – Eindhoven University of Technology: LHP2014 Energy Efficient Facade Lighting
Saeid Asadollahi – Eindhoven University of Technology: Infographic Workshop Developing a Geo-fencing-based Safety System for Buried High-pressure Pipelines
dr. **Serdar Aşut** – Delft University of Technology: LHP2017 Reprrinting Architectural Heritage
ir. **Juan Azcarate** – Delft University of Technology: Research to Reality, R2R Facade Leasing
ir. **Siebe Bakker** – bureaubakker: curator 4TU.Bouw, Conversations on Research to Reality, Future Formats for Applied Research, Real Additive Manufacturing: Real | Dream, City of Things, Real Additive Manufacturing: Prototype | Production, Research tot Reality Bootcamp & Conference, City of Realities, Infographics Workshops, de Toekomst wordt Gebouwd, Built Society Smart Reality, Smart Liveable Cities, Annual 'Newspapers', Week van de Bouw 2015, GEVEL2016, Infratech 2017, Bouwbeurs 2017, GEVEL2018, Lighthouse Projects Evaluation
ir. **Lida Barou** – Delft University of Technology: LHP2016 Restorative Glass, LHP2017 Re3 Glass, Research to Reality
prof.dr. **Jakob Beetz** – Eindhoven University of Technology: LHP2014 Semantic Web of Building Information, LHP2017 ExcaSafeZone
prof.ir. **Juliette Bekkering** – Eindhoven University of Technology: LHP2016 Public Space for Refugees, LHP2017 Reprinting Architectural Heritage, Real Additive Manufacturing: 3D Concrete Printing
Chiel Bekkers – Eindhoven University of Technology: LHP2014 Robotically Driven Construction of Buildings
Diewertje ten Berg MSc. – University of Twente: Infographic Workshop ROC Utility Surveyor
John van den Berg – Delft University of Technology: LHP2017 GeoCon Bridge
Marc van den Berg MSc. – University of Twente: Infographic Workshop End-of-life Coordination**,** Infographic Workshop Experiencing Supply Chain Optimizations
dr. **Maya van den Berg** – Universiteit Twente: Smart Liveable Cities
dr.ir. **Pauline van den Berg** – Eindhoven University of Technology: LHP2016 Solar Bikes: User Acceptance, Research to Reality
ir. **Pieter Beurskens** – University of Twente: LHP2017 Re3 Glass
Dr.-Ing. **Henriette Bier** – Delft University of Technology: Future Formats for Applied Research, LHP2014 Robotically Driven Construction of Buildings, LHP2017 Adaptive Joints with Variable Stiffness, Research to Reality, Real Additive Manufacturing: Real | Dream
dr. **Nimish Biloria** – Delft University of Technology: LHP2016 Fibrous Smart Materials
Dr.-Ing. **Marcel Bilow** – Delft University of Technology: Innovation Expo Amsterdam 2016, LHP2014 The LIGHTVAN, LHP2015 PD Lab, LHP2016 CAST Formwork System, Real Additive Manufacturing: Prototype | Production, Research to Reality
Aaron Bislip – Delft University of Technology: GEVEL2016 Real Additive Manufacturing Workshop
prof.dr.ir. **Bert Blocken** – Eindhoven University of Technology: PDENG A Living Lab, PDENG A Living Lab, PDENG Air Curtain Optimization
ir. **Rijk Blok** – Eindhoven University of Technology: LHP2016 Bio Based Bridge, LHP2016 CAST Formwork System, Research to Reality
Ton Blom – Delft University of Technology: LHP2017 GeoCon Bridge
ir. **Serban Bodea** – Delft University of Technology: LHP2014 Robotically Driven Construction of Buildings
Jan de Boer – Delft University of Technology: Research to Reality
dr. **Regina Bokel** – Delft University of Technology: LHP2015 Throw in the I-drone, City of Things – Hackathon
ing. **Wout van Bommel** – Eindhoven University of Technology: LHP2014 DoubleFace
Sjonnie Boonstra MSc. – Eindhoven University of Technology: Research to Reality

Chris Borg Costanzi MSc. – Delft University of Technology: LHP2016 Double Curved Concrete Printing, Real Additive Manufacturing: Prototype | Production, Research to Reality
dr.ir. **Freek Bos** – Eindhoven University of Technology: LHP2016 Double Curved Concrete Printing, LHP2016 Optimising 3D Concrete Printing, LHP2017 3D Concrete Printing for Structural Applications, Real Additive Manufacturing: 3D Concrete Printing, Research to Reality
Albert Bosman – Delft University of Technology: LHP2017 Geocon Bridge
ir. **Bram Botterman** – Eindhoven University of Technology: LHP2016 Sound Absorbing Glass, Research to Reality
Ella Braat-Eggen MSc. – Eindhoven University of Technology: Research to Reality, R2R Noise in Open-plan Study Environments
Daan Brinkerink – University of Twente: LHP2016 Smart Sensors in Asphalt
ir. **Telesilla Bristogianni** – Delft University of Technology: LHP2016 Restorative Glass, LHP2017 Re3 Glass, Research to Reality
ing. **Cor de Bruijn** – Eindhoven University of Technology: Real Additive Manufacturing: 3D Concrete Printing
Marijn Bruurs – Eindhoven University of Technology: LHP2014 Robotically Driven Construction of Buildings
dr. **Marleen Buizer** – Wageningen University and Research: Smart Liveable Cities
Adrie van der Burgt MSc. – Eindhoven University of Technology: LHP2014 Robotically Driven Construction of Buildings
Riccardo Capperucci MSc. – Eindhoven University of Technology: LHP2015 Leafroof
Ulric Celada MSc. – Delft University of Technology: LHP2017 Geocon Bridge
Joyraj Chakraborty – University of Twente: LHP2016 Smart Sensors in Asphalt, Research to Reality
Carissa Champlin – University of Twente: Infographic Workshop Codesigning Planning Support (Systems)
Stefan Chaves Figueiredo MSc. – Delft University of Technology: LHP2017 3D Concrete Printing for Structural Applications
M-Arch. **Hung-Chu Chen** – Eindhoven University of Technology: R2R Adapting to Future Climate Through Land Use
dr.ir. **Jeroen Coenders** – Delft University of Technology: LHP2016 Optimising 3D Concrete Printing, LHP2016 Optimising 3D Concrete Printing, Real Additive Manufacturing: Prototype | Production
prof.dr. **Bernard Colenbrander** – Eindhoven University of Technology: LHP2015 Architectures of the Black Gold, LHP2015 Saving Energy Battle
ir. **Mark Cox** – Eindhoven University of Technology: LHP2015 Leafroof
T.C. Dai – Delft University of Technology: City of Realities
dr. **Gamze Dane** – Eindhoven University of Technology: Research to Reality
ir. **Priya Darshini Cheyyar Nageswaran** – University of Twente: Infographic Workshop Design Guide Operational Strategies for Asphalt Compaction, Research to Reality
dr. **Michael Debije** – Eindhoven University of Technology: LHP2015 Leafroof, LHP2015 Polyarch, PDENG Luminescent Solar Concentrator
Matthijs de Deckere – Delft University of Technology: City of Things – Hackathon
Arjen Deetman – Eindhoven University of Technology: LHP2017 Happy Senior Living
prof.dr. **Geert Dewulf** – University of Twente
Marloes Dignum – Delft University of Technology: Smart Liveable Cities
Sjon van Dijk – University of Twente: LHP2015 RFID Sensors
prof.dr.ir. **Joris Dik** – Delft University of Technology: LHP2017 Reprinting Architectural Heritage
ir. **Kornelia Dimitrova** – Eindhoven University of Technology: LHP2016 Public Space for Refugees
Eline Dolkemade – Eindhoven University of Technology: LHP2016 SPONG3D
Eleonora di Domenica – Delft University of Technology: LHP2014 Robotically Driven Construction of Buildings

prof.dr.ir.ing. **André Dorée** – University of Twente: Ambassador 4TU.Bouw, Scientific Director 4TU.Bouw 2018 onwards, PDENG A Sustainable Life-cycle Method, Research to Reality
ir.ing. **Guillaume Doudart de la Grée** – Eindhoven University of Technology: LHP2015 Leafroof
Chengcheng Du – Delft University of Technology: LHP2017 Geocon Bridge
Diruij Dugarte Manoukian MSc. – University of Twente: PDENG A Sustainable Life-cycle Method
Xander den Duijn BSc. – Delft University of Technology: LHP2016 Spying the Underground
dr. **Elma Durmisevic** – University of Twente: LHP2017 Re3 Glass
ir. **Randy van Eck** – Eindhoven University of Technology: PDENG Sustainable Performance Optimization
Peter Eigenraam MSc. – Delft University of Technology: LHP2014 Kine-Mould
Hisham El Ghazi – Eindhoven University of Technology: LHP2014 Kine-Mould
dr.ir. **Bram Entrop** – University of Twente: LHP2014 Impenetrable Infiltration, LHP2015 Throw in the I-drone
Mark van Erk – Delft University of Technology: LHP2016 SPONG3D, Research to Reality
prof.dr.ir. **Sandra Erkens** – Delft University of Technology: LHP2015 RFID Sensors, LHP2016 Smart Sensors in Asphalt
Nico Eurelings – Eindhoven University of Technology: PDENG De Reus van Schimmert
Miktha Farid Alkadri MSc. – Delft University of Technology: LHP2017 Reprinting Architectural Heritage, Research to Reality
Else Ferf Jentink – Eindhoven University of Technology: LHP2015 Saving Energy Battle
Radoslaw Flis – Delft University of Technology: LHP2014 Robotically Driven Construction of Buildings
Judith Fraune – Delft University of Technology / KNOB: City of Realities
Arno Freeke – Delft University of Technology: City of Realities
Giulia Frigo – Delft University of Technology: LHP2017 Re3 Glass
Isabella Gaetani dell'Aquila d'Aragona – Eindhoven University of Technology: PDENG A Living Lab
Marco Galli – Delft University of Technology: LHP2014 Robotically Driven Construction of Buildings
prof.ir. **Dick van Gameren** – Delft University of Technology: LHP2017 Happy Senior Living
prof. ir. **Ivan Gavran** – Delft University of Technology: LHP2014 Kine-Mould
prof.dr.ir. **Bert Geerken** – Delft University of Technology
Immanuel Geesing MSc. – Eindhoven University of Technology: PDENG Industrial Symbiosis Software
Luc Gerlings – Eindhoven University of Technology: LHP2014 Robotically Driven Construction of Buildings
prof.dr.ing. **Karst Geurs** – University of Twente: LHP2016 Solar Bikes: User Acceptance
dr. **Bahman Ghiassi** – Delft University of Technology: LHP2017 Geocon Bridge, Research to Reality
dr. **Madeleine Gibescu** – Eindhoven University of Technology: PDENG De Reus van Schimmert, PDENG Transition Towards DC Mirco Grids
Bas Giskes – Eindhoven University of Technology: PDENG A Living Lab
ir. **Rafail Gkaidatzis** – Delft University of Technology: LHP2016 Bio Based Bridge
Michael Gravers – Eindhoven University of Technology: LHP2015 Saving Energy Battle
dr.ir. **Steffen Grünewald** – Delft University of Technology: LHP2014 Kine-Mould
Jia Guo – Eindhoven University of Technology: Research to Reality
ir. **Arjan Habraken** – Eindhoven University of Technology: Research to Reality
Anahita Haghparast – Eindhoven University of Technology: LHP2015 Saving Energy Battle

ir. **Eric van den Ham** – Delft University of Technology: LHP2015 Polyarch, LHP2015 Throw in the I-drone
dr.ir. **Mohamed Hamdy Hassan** – Eindhoven University of Technology: PDENG A Living Lab
John Hanna – Delft University of Technology: LHP2017 Reprinting Architectural Heritage, Research to Reality
prof.dr. **Timo Hartmann** – University of Twente: LHP2014 Semantic Web of Building Information, PDENG A Sustainable Life-cycle Method
Bahman Hashemi – Eindhoven University of Technology: Research to Reality, R2R Fatigue Partial Factors for Bridges
Lisanne Havinga – Eindhoven University of Technology: LHP2015 Saving Energy Battle
prof.ir. **Rob van Hees** – Delft University of Technology: LHP2016 Restorative Glass
prof.dr.ing. **Carola Hein** – Delft University of Technology: City of Realities, LHP2015 Architectures of the Black Gold, LHP2017 Reprinting Architectural Heritage, Research to Reality
Dipl.-Ing. **Florian Heinzelmann** – Eindhoven University of Technology: LHP2014 DoubleFace
dr.ir. **Alexandra den Heijer** – Delft University of Technology: R2R Facade Leasing
ir. **Eefje Hendriks** – Eindhoven University of Technology: Infographic Workshop Effective Knowledge Exchange Tools, LHP2016 Public Space for Refugees
prof.dr.ir. **Jan Hensen** – Eindhoven University of Technology: LHP2014 Impenetrable Infiltration, LHP2015 Polyarch, LHP2016 Convective Concrete, LHP2016 SPONG3D, PDENG A Living Lab
Luuk Hermans – Eindhoven University of Technology: LHP2015 Saving Energy Battle
dr.ir. **Dirk van den Heuvel** – Delft University of Technology: LHP2017 Happy Senior Living
Arwin Hidding – Delft University of Technology: LHP2017 Adaptive Joints with Variable Stiffness
Stef Hoeijmakers – Delft University of Technology: LHP2014 Robotically Driven Construction of Buildings
dr.ir. **Pieter-Jan Hoes** – Eindhoven University of Technology: PDENG A Living Lab
dr.ir. **Frank van der Hoeven** – Delft University of Technology: Ambassador 4TU. Bouw, City of Realities, City of Things, Future Formats for Applied Research, Innovation Expo Amsterdam 2016, Research to Reality, Smart Liveable Cities, R2R Syntactic and/or Configraphic
dr.ir. **Herm Hofmeyer** – Eindhoven University of Technology: R2R Excellent Building Performance
ir. **Sjef van Hoof** – Eindhoven University of Technology: LHP2016 Public Space for Refugees
dr.ir. **Twan van Hooff** – Eindhoven University of Technology: PDENG Air Curtain Optimization
Ruth Hoogenraad – Delft University of Technology: LHP2014 Robotically Driven Construction of Buildings
Mitchel Hoos – Eindhoven University of Technology: LHP2014 Energy Efficient Facade Lighting
prof.dr.ir. **Dick Hordijk** – Delft University of Technology: LHP2017 Geocon Bridge
assoc.prof.dr. **Truus Hordijk** – Delft University of Technology: Future Formats for Applied Research, LHP2014 Energy Efficient Facade Lighting, LHP2014 The LIGHTVAN, LHP2015 Polyarch, Research to Reality
dr.ir. **Maarten Hornikx** – Eindhoven University of Technology: LHP2016 Sound Absorbing Glass, R2R Noise in Open-plan Study Environments
Enayat Hosseini Aria – Delft University of Technology: Research to Reality
dr. **Siavash Hosseinyalamdary** – University of Twente: Research to Reality
Geert-Jan Houben – Delft University of Technology: Smart Liveable Cities
Zhekang Huang – Delft University of Technology: LHP2017 Geocon Bridge
Chen Hung Chu – Eindhoven University of Technology: Research to Reality
Ramon ter Huurne – University of Twente: Infographic Workshop Modelling Subsurface Infrastructure by Developing a Domain Ontology
Thijs IJperlaan – Delft University of Technology: LHP2014 Robotically Driven Construction of Buildings
Firat Isik – Delft University of Technology: City of Realities
ir. **Erwin Jacobs** – Delft University of Technology: LHP2017 Re3 Glass, Research to Reality
Mitchell Janmaat – Eindhoven University of Technology: LHP2014 Kine-Mould
Wen Jiang – Eindhoven University of Technology: Research to Reality
Hans de Jonge – Delft University of Technology: LHP2014 Robotically Driven Construction of Buildings
ir. **Javid Jooshesh** – Delft University of Technology: LHP2016 Fibrous Smart Materials, Research to Reality
Mohammad Jooshesh Oana Anghelache – Delft University of Technology: LHP2014 Robotically Driven Construction of Buildings
Sandra K. Sánchez de la Garza – Eindhoven University of Technology: LHP2015 Saving Energy Battle
Steph Kanters – Delft University of Technology: LHP2014 Robotically Driven Construction of Buildings
Parisa Khademagha – Eindhoven University of Technology: Infographic Workshop Nature Inspired Healthy Light in the Built Environment
dr.ir. **Tilllmann Klein** – Delft University of Technology: Future Formats for Applied Research, LHP2015 PD Lab, LHP2015 Polyarch, R2R Facade Leasing
Marie de Klijn-Chevalerias MSc. – Eindhoven University of Technology: LHP2016 Convective Concrete, LHP2016 SPONG3D, Research to Reality
prof.Dr.-Ing **Ulrich Knaack** – Delft University of Technology: Scientific Director 4TU. Bouw 2014 – 2017, Built Society Smart Reality, De Toekomst Wordt Gebouwd, LHP2016 Convective Concrete, LHP2016 SPONG3D, LHP2017 Reprinting Architectural Heritage, PDENG, Real Additive Manufacturing: Real | Dream, Real Additive Manufacturing: Prototype | Production, Research to Reality
prof.dr. **Armin Kohlrausch** – Eindhoven University of Technology: R2R Noise in Open-plan Study Environments
Karin Kompatscher – Eindhoven University of Technology: Infographic Workshop Microclimate Control for Cultural Heritage
dr.ing. **Thaleia Konstantinou** MSc. – Delft University of Technology: LHP2016 SPONG3D, Research to Reality
Peter Koorstra – Delft University of Technology: LHP2017 Reprinting Architectural Heritage
Michal Kornecki – Delft University of Technology: LHP2014 Robotically Driven Construction of Buildings
dr.ir. **Alexander Koutamanis** – Delft University of Technology: LHP2014 Semantic Web of Building Information, LHP2015 Architectures of the Black Gold
ir. **Thomas Krijnen** – Eindhoven University of Technology: LHP2014 Semantic Web of Building Information
Arend-Jan Krooneman – Delft University of Technology: City of Realities
Rick Krosenbrink MSc. – Delft University of Technology: LHP2016 Public Space for Refugees
Laurie van Krugten – Eindhoven University of Technology: LHP2015 Saving Energy Battle
dr. **Zachar Krumer** – University of Twente: LHP2015 Leafroof
ir. **Barbara Kuit** – Eindhoven University of Technology: LHP2017 Reprinting Architectural Heritage
dr. **Anupam Kumar** – Delft University of Technology: LHP2015 RFID Sensors, Research to Reality
Han La Poutre – Delft University of Technology / CWI Amsterdam: Smart Liveable Cities
ir. **Paul Lagendijk** – Delft University of Technology: LHP2017 Geocon Bridge
Giorgio Larcher – Eindhoven University of Technology: LHP2017 Happy Senior Living
Maiko van Leeuwen – Delft University of Technology: LHP2017 Geocon Bridge

Bart Lenderink – University of Twente: Infographic Workshop Public Pocurement of Innovation
Davide Leonetti Msc. – Eindhoven University of Technology: Research to Reality, R2R Fatigue Partial Factors for Bridges
Qingpeng Li – Delft University of Technology: Research to Reality
Wenshu Li – Eindhoven University of Technology: Research to Reality
Feixiong Liao – Eindhoven University of Technology: Research to Reality
prof.dr.ir. **Jos Lichtenberg** – Eindhoven University of Technology: LHP2015 PD Lab, PDENG Luminescent Solar Concentrator
Arthur van Lier – Eindhoven University of Technology: LHP2016 SPONG3D
Jeroen van Lit – Delft University of Technology: LHP2014 Robotically Driven Construction of Buildings
Jonh Liu – Delft University of Technology: LHP2017 Geocon Bridge
dr.ir. **Xueyan Liu** – Delft University of Technology: LHP2015 RFID Sensors, LHP2016 Smart Sensors in Asphalt
dr.ir. **Marcel Loomans** – Eindhoven University of Technology: LHP2014 Impenetrable Infiltration, Healthy Learning Environment
ir. **Roel Loonen** – Eindhoven University of Technology: LHP2016 Convective Concrete, LHP2016 SPONG3D, Research to Reality
Somayeh Lotfi – Delft University of Technology: LHP2014 Robotically Driven Construction of Buildings
dr.ir. **Christian Louter** – Delft University of Technology: Research to Reality
Perry Low – Delft University of Technology: LHP2014 Robotically Driven Construction of Buildings
dr.ir. **Mladena Lukovic** – Delft University of Technology: Research to Reality, LHP2017 Geocon Bridge
Tobi Lusing – Eindhoven University of Technology: LHP2014 Kine-Mould
Fatemeh Mahmoudi – University of Twente: Infographic Workshop Safe Fibre Installation
Denis Makarov – University of Twente: Infographic Workshop Real-time Process Control System for Asphalt Paving and Compacting, LHP2015 RFID Sensors, Research to Reality
prof.dr.ir. **Johan Maljaars** – Eindhoven University of Technology: R2R Fatigue Partial Factors for Bridges
Pascal Martens – Delft University of Technology: LHP2016 Optimising 3D Concrete Printing
Maarten Mathot – Delft University of Technology: LHP2016 Optimising 3D Concrete Printing
ir. **Winfried Meijer** – Delft University of Technology: LHP2014 DoubleFace
Maryam Meshkinkiya – Eindhoven University of Technology: Infographic Workshop Uncertainty Quantification of Incident Reflected Solar Radiation
Thomas Meut – Delft University of Technology: City of Realities
Mattias Michel – Delft University of Technology: LHP2014 Kine-Mould
dr.ir. **Seirgei Miller** – University of Twente: LHP2015 RFID Sensors, LHP2016 Smart Sensors in Asphalt
dr.ir. **Faas Moonen** – Eindhoven University of Technology: LHP2016 CAST Formwork System
Yaron Moonen – Eindhoven University of Technology: LHP2017 TERRA–ink
Rob Moors – Delft University of Technology: LHP2014 Robotically Driven Construction of Buildings
Sina Mostafavi M. Arch. – Delft University of Technology: Future Formats for Applied Research, LHP2014 Robotically Driven Construction of Buildings, Research to Reality
Guus Mostart – Delft University of Technology: LHP2014 Robotically Driven Construction of Buildings
Koen Mulder – Delft University of Technology: Research to Reality
Marija Nedeljković MSc. – Delft University of Technology: LHP2017 Geocon Bridge
prof.ir. **Elphi Nelissen** – Eindhoven University of Technology: Smart Liveable Cities

Susan Ng-A-Tham – Delft University of Technology: City of Realities
prof.ir. **Rob Nijsse** – Delft University of Technology: LHP2016 Restorative Glass, LHP2017 Re3 Glass
prof.dr. **Ed Nijssen** – Eindhoven University of Technology: PDENG De Reus van Schimmert
Pirouz Nourian – Delft University of Technology: Research to Reality, R2R Syntactic and/or Configraphic, City of Things – Hackathon
Anna Maria Ntarladima MSc. – Delft University of Technology: Research to Reality, LHP2016 Spying the Underground
Maria Odete Magalhães de Almeida – Eindhoven University of Technology: PDENG A Living Lab
ir. **Faidra Oikonomopoulou** – Delft University of Technology: LHP2016 Restorative Glass, LHP2017 Re3 Glass, Research to Reality
dr. **Léon olde Scholtenhuis** – University of Twente: Infographic Workshop Professionalize Ground Radar Usage, LHP2016 Spying the Underground, LHP2017 ExcaSafeZone, Research to Reality
dr. **Ioulia Ossokina** – Eindhoven University of Technology: LHP2017 65+ Best Neighbourhood Concepts: Happy Senior Living, LHP2017 Happy Senior Living, Research to Reality
Jan Paclt – Delft University of Technology: LHP2014 Robotically Driven Construction of Buildings
Liviu Paicu – Delft University of Technology: City of Realities
Xiaoteng Pan – Eindhoven University of Technology: Research to Reality
ir. **Argyrios Papadopoulos** MEng. – Eindhoven University of Technology: LHP2015 Leafroof, PDENG A Living Lab
dr. **Pieter Pauwels** – Eindhoven University of Technology: LHP2017 ExcaSafeZone
Dejian Peng – Delft University of Technology: City of Realities
Ana Pereira Roders – Eindhoven University of Technology: LHP2015 Saving Energy Battle
Evi Ploumpidou – Eindhoven University of Technology: PDENG Transition Towards DC Mirco Grids
Bayu Prayudhi – Delft University of Technology: GEVEL2016 Real Additive Manufacturing Workshop
Silke Prinsse MSc. – Delft University of Technology: LHP2017 Geocon Bridge
Janine Profijt – University of Twente: Infographic Workshop Blended Learning, Research to Reality
ir. **Arno Pronk** – Eindhoven University of Technology: LHP2014 Kine-Mould, LHP2016 SPONG3D, LHP2017 TERRA–ink, Research to Reality
Patrycja Pustelnik – Eindhoven University of Technology: Research to Reality
dr. **Han Qi** – Eindhoven University of Technology: R2R Adapting to Future Climate Through Land Use
Berend Raaphorst – Delft University of Technology: LHP2014 Robotically Driven Construction of Buildings
Paulina Racz – University of Twente: Infographic Workshop Improved Strategies, Logic and Decision Support for Selecting Test Trench Locations
prof.dr. **Angèle Reinders** – University of Twente: LHP2015 Leafroof
prof.dr. **Peter Rem** – Delft University of Technology: LHP2014 Robotically Driven Construction of Buildings
Nadia Remmerswaal MSc. – Delft University of Technology: Innovation Expo Amsterdam 2016, LHP2016 CAST Formwork System, Research to Reality
prof.ir. **Michiel Riedijk** – Delft University of Technology: LHP2016 Public Space for Refugees
Erwin van Rijbroek – Eindhoven University of Technology: LHP2014 Kine-Mould
Michiel Ritzen – Eindhoven University of Technology: Research to Reality, R2R Exploration of Building
Iris Rombouts – Eindhoven University of Technology: LHP2014 Robotically Driven Construction of Buildings
Claudia Romero Rodriguez MSc. – Delft University of Technology: LHP2017 3D Concrete Printing for Structural Applications

prof.dr. **Sjoerd Romme** – Eindhoven University of Technology: PDENG Transition Towards DC Mirco Grids
Bas Rongen – Eindhoven University of Technology: LHP2016 Bio Based Bridge
Rutger Roodt – Delft University of Technology: LHP2014 Robotically Driven Construction of Buildings
Job Roos – Delft University of Technology: LHP2015 Saving Energy Battle
prof.Dr.-Ing.habil. **Alexander Rosemann** – Eindhoven University of Technology: Future Formats for Applied Research, LHP2014 Energy Efficient Facade Lighting, LHP2014 The LIGHTVAN, LHP2015 Leafroof, LHP2015 Polyarch
prof.dr.ir. **Jan Rots** – Delft University of Technology
Wout Rouwhorst – Eindhoven University of Technology: LHP2014 Robotically Driven Construction of Buildings
Twan Rovers – University of Twente: Infographic Workshop Redesign Quality Label
ir. **Paul, de Ruiter** – Delft University of Technology: LHP2014 DoubleFace, LHP2016 SPONG3D, LHP2016 Unleash the Building Bots, Real Additive Manufacturing: Prototype | Production, Research to Reality
prof.Dipl.-Ing. **Peter Russel** – Delft University of Technology
Siert Saes – Eindhoven University of Technology: LHP2014 Robotically Driven Construction of Buildings
Panos Sakkas – Delft University of Technology: Research to Reality
prof.dr.ir. **Theo Salet** – Eindhoven University of Technology: LHP2014 Robotically Driven Construction of Buildings, LHP2017 3D Concrete Printing for Structural Applications, Real Additive Manufacturing: 3D Concrete Printing
Valentini Sarakinioti – Delft University of Technology: Real Additive Manufacturing: Prototype | Production, Research to Reality
prof.dr.ir. **Sevil Sariyildiz** – Delft University of Technology: R2R Syntactic and/or Configraphic
Ali Sarmad – Delft University of Technology: GEVEL2016 Real Additive Manufacturing Workshop
dr.ir. **Henk Schellen** – Eindhoven University of Technology: LHP2015 Saving Energy Battle, LHP2016 Restorative Glass
Max van Schendel – Delft University of Technology: City of Realities
prof.dr. **Albert Schenning** – Eindhoven University of Technology: LHP2015 Polyarch
dr.ir. **Jos van Schijndel** – Eindhoven University of Technology: LHP2016 Restorative Glass
dr.ir. **Roel Schipper** – Delft University of Technology: LHP2014 Kine-Mould, LHP2016 Double Curved Concrete Printing, Real Additive Manufacturing: Prototype | Production, Research to Reality
prof.dr.ir. **Erik Schlangen** – Delft University of Technology: Ambassador 4TU.Bouw, Research to Reality
ir. **Alexander Schmets** – Delft University of Technology: Executive Director 4TU. Bouw 2014 – 2017, Built Society Smart Reality, De Toekomst Wordt Gebouwd, PDENG, Research to Reality, Smart Liveable Cities
Torsten Schröder – Eindhoven University of Technology: Research to Reality
Niek Schuijers – Eindhoven University of Technology: LHP2014 Kine-Mould
dr.ir. **Seyed Sedighi** – Delft University of Technology: LHP2015 Architectures of the Black Gold, Research to Reality
Foteini Setaki MSc. Arch. – Delft University of Technology: LHP2017 TERRA–ink, Research to Reality
Eirini Sfakiotaki – Eindhoven University of Technology: LHP2015 Saving Energy Battle
Kasper Siderius – Delft University of Technology: LHP2014 Robotically Driven Construction of Buildings
Stefan Slangen – Eindhoven University of Technology: LHP2017 TERRA–ink
Ruth Sloot – Universiteit Twente: Infographic Workshop How to Incentivy the Use of BIM
ir. **Joris Smits** – Delft University of Technology: LHP2016 Bio Based Bridge
Joost Snels – Wageningen University and Research: Smart Liveable Cities
ir. **Ate Snijder** – Delft University of Technology: LHP2016 Sound Absorbing Glass

prof.ir. **Bert Snijder** – Eindhoven University of Technology: R2R Fatigue Partial Factors for Bridges
Matteo Soru MSc. – Delft University of Technology: LHP2014 Kine-Mould
Tim Span – Eindhoven University of Technology: LHP2014 Robotically Driven Construction of Buildings
dr.ir. **Stefan van der Spek** – Delft University of Technology: City of Things – Hackathon, City of Realities
dr.ir. **Willem van der Spoel** – Delft University of Technology: LHP2014 DoubleFace
Piet van Staalduinen – Delft University of Technology: Research to Reality, Smart Liveable Cities
Maarten van Steen – Universiteit Twente: Smart Liveable Cities
dr. **Irina Stipanovic** – University of Twente: PDENG A Sustainable Life-cycle Method
ir. **Femke Stout** – Eindhoven University of Technology: LHP2015 Architectures of the Black Gold
ir. **Pieter Stoutjesdijk** – Delft University of Technology: LHP2015 PD Lab
ir. **Anne Struiksma** – Delft University of Technology: LHP2016 Sound Absorbing Glass, Research to Reality
dr.ir. **Akke Suiker** – Eindhoven University of Technology: R2R Excellent Building Performance
M. Teeling MArch. – Delft University of Technology: LHP2016 SPONG3D
dr.ir. **Martin Tenpierik** – Delft University of Technology: Future Formats for Applied Research, LHP2014 DoubleFace, LHP2016 Sound Absorbing Glass, LHP2016 SPONG3D, Research to Reality
prof.Dr.-Ing. **Patrick Teuffel** – Eindhoven University of Technology: LHP2014 DoubleFace, LHP2016 Bio Based Bridge, LHP2016 SPONG3D, LHP2017 Adaptive Joints with Variable Stiffness, LHP2017 TERRA–ink, Real Additive Manufacturing: 3D Concrete Printing
Evangelos Theocharous MSc. – Delft University of Technology: LHP2016 Spying the Underground, Research to Reality
Arjan Thijssen – Delft University of Technology: LHP2017 Geocon Bridge
ir. **Wiwi Tjiook** – Indonesian Dispora Network: Research to Reality
Leon Tonnaer – Eindhoven University of Technology: LHP2015 Saving Energy Battle
dr.ir. **Ignacio Torrens Galdiz** – Eindhoven University of Technology: PDENG A Living Lab
Tugce Tosun-Uslu MSc. – Eindhoven University of Technology: PDENG Luminescent Solar Concentrator
dr. **Michela Turrin** MArch. – Delft University of Technology: Future Formats for Applied Research, Innovation Expo Amsterdam 2016, LHP2014 DoubleFace, LHP2016 SPONG3D, LHP2017 Reprinting Architectural Heritage, LHP2017 TERRA–ink, Real Additive Manufacturing: Prototype | Production, Research to Reality
Konstantinos Tzanakakis – Eindhoven University of Technology: PDENG De Reus van Schimmert
dr. **Farid Vahdatikhaki** – University of Twente: LHP2017 ExcaSafeZone, Research to Reality
ing. **Maria Valentini Sarakinioti** MSc. – Delft University of Technology: LHP2016 SPONG3D
dr. **Alexandr Vasenev** – University of Twente: LHP2015 Throw in the I-drone
Pintip Vayarothai – University of Twente: Infographic Workshop Intergated Decision Model for Selecting Public Investment Projects
dr.ir. **Fred Veer** – Delft University of Technology: LHP2016 Restorative Glass, LHP2016 Sound Absorbing Glass, LHP2017 Re3 Glass, LHP2017 TERRA–ink
Jurian van der Vegt – University of Twente: LHP2016 Smart Sensors in Asphalt
Tommaso Venturini – Delft University of Technology: LHP2017 TERRA–ink, Research to Reality
Martijn Verboord – Eindhoven University of Technology: LHP2014 Kine-Mould
Edward Verbree – Delft University of Technology: Research to Reality
Robin Versteeg – Eindhoven University of Technology: LHP2014 Kine-Mould
ir. **Rob Vervoort** – Eindhoven University of Technology: PDENG Aerodynamic

Optimization of Particulate Matter Removal Using Positive Ionization Units
ing. **Lars van Vianen** – Delft University of Technology: LHP2015 Architectures of the Black Gold
Stephanie Villegas Martinez MSc. – Eindhoven University of Technology: Future Formats for Applied Research, PDENG Healthy Learning Environment
Christiaan Voorend – Eindhoven University of Technology: LHP2014 Robotically Driven Construction of Buildings
Rens Vorstermans – Eindhoven University of Technology: LHP2016 SPONG3D, LHP2017 TERRA–ink
Jordy Vos – Eindhoven University of Technology: LHP2014 Robotically Driven Construction of Buildings
Jan Vreeburg – Wageningen University and Research: Smart Liveable Cities
prof.dr.ir. **Bauke de Vries** – Eindhoven University of Technology: Ambassador 4TU. Bouw, PDENG Industrial Symbiosis Software, PDENG Sustainable Performance Optimization, Research to Reality, Smart Liveable Cities, R2R Adapting to Future Climate Through Land Use, R2R Excellent Building Performance
Marieke de Vries – Eindhoven University of Technology: LHP2014 Robotically Driven Construction of Buildings
Nina Waldhauer – Wageningen University and Research: Smart Liveable Cities
Alex Wandl – Delft Unversity of Technology: Research to Reality
ir. **Qinyu Wang** – Eindhoven University of Technology: LHP2017 Adaptive Joints with Variable Stiffness, Research to Reality
prof.dr.ir. **Pieter van Wesemael** – Eindhoven University of Technology: PDENG A Living Lab
Wies Westerhout – Eindhoven University of Technology: LHP2014 Energy Efficient Facade Lighting
Bas van Wezel – Eindhoven University of Technology: LHP2014 Robotically Driven Construction of Buildings
prof. ir. **Simon Wijte** – Eindhoven University of Technology: LHP2017 Geocon Bridge
Tim Willems – Eindhoven University of Technology: LHP2015 Saving Energy Battle
Wessel Wits – University of Twente: Real Additive Manufacturing: Real | Dream
Dennis de Witte MSc. – Delft University of Technology: LHP2016 Convective Concrete, GEVEL2016 Real Additive Manufacturing Workshop, Real Additive Manufacturing: Dream | Real, Real Additive Manufacturing: Prototype | Production
Rob Wolfs MSc. – Eindhoven University of Technology: LHP2014 Robotically Driven Construction of Buildings, LHP2016 Double Curved Concrete Printing, LHP2016 Optimising 3D Concrete Printing, Real Additive Manufacturing: Dream | Real, Real Additive Manufacturing: 3D Concrete Printing
Danhua Xu – Delft University of Technology: City of Realities
Alexander Yarovoy – Delft University of Technology: Smart Liveable Cities
Peyvand Yavari – Eindhoven University of Technology: LHP2015 Saving Energy Battle
dr. **Guang Ye** – Delft University of Technology: LHP2017 Geocon Bridge
Meisam Yousefzadeh MSc. – University of Twente: PDENG Geometric Information Generator
Cas van der Zanden – Delft University of Technology: Research to Reality
Aant van der Zee – Eindhoven Universty of Technology: LHP2016 Unleash the Building Bots, Real Additive Manufacturing: Prototype | Production, Research to Reality
Kaiyi Zhu – Delft University of Technology: City of Realities
prof.Dr.-Ing. **Sisi Zlatanova** – Delft University of Technology: LHP2016 Spying the Underground, LHP2017 ExcaSafeZone

INDUSTRY & INSTITUTIONS

100% Research: LHP2014 Robotically Driven Construction of Buildings
3DGeosolutions Co.: PDENG Geometric Information Generator
ABT: LHP2016 Restorative Glass
Alcoa | Kawneer: R2R Facade Leasing
Aldowa: R2R Facade Leasing
dr. **Patricia Alkhoven** – Meertens Instituut: City of Realities
Alkondor: R2R Facade Leasing
AluEco | VMRG: R2R Facade Leasing
Bao An Nguyen Phuoc – UNStudio: City of Realities
Stefanos Andreou – Volunteer Amsterdam: LHP2015 Saving Energy Battle
Martje van Ankeren – Nationaal Regieorgaan Praktijkgericht Onderzoek Sia: Smart Liveable Cities
Pauline Arts MSc. – Ministerie van Veiligheid en Justitie: Smart Liveable Cities
Atelier Robotic: LHP2016 Fibrous Smart Materials
Avans University of Applied Sciences: LHP2016 Bio Based Bridge, R2R Noise in Open-plan Study Environments
ing. **Jan Averink** – Selekthuis Bouwgroep: LHP2014 Impenetrable Infiltration
prof.dr. **Thomas Back** – Leiden University: R2R Excellent Building Performance
Henk Bakker – Gemeente Den Haag: LHP2015 Saving Energy Battle
Balast Nedam: LHP2014 Semantic Web of Building Information, Real Additive Manufacturing: 3D Concrete Printing
David Beckett: Research to Reality – Bootcamp
Wouter Beelen – VolkerWessels iCity: Research to Reality
Bekaert: Real Additive Manufacturing: 3D Concrete Printing
Jur Bekooy – Foundation for Old Groningen Churches: LHP2017 Reprinting Architectural Heritage
Thijs Bennebroek – Vereniging Hendrick de Keyser: City of Realities
Beroepsvereniging Het Zwarte Corps: LHP2017 ExcaSafeZone
prof. dr. ir. **Luca Bertolini** – Universiteit van Amsterdam: Smart Liveable Cities
Nienke Binnendijk – Recycled Island Stichting: Future Formats for Applied Research
ir. **Koen van der Blom** – Leiden University: R2R Excellent Building Performance
Teun Bokhoven MSc. – TS Energie, TKI Urban Energy: Smart Liveable Cities
Tobias Bonten – Leiden Universitair Medisch Centrum: Smart Liveable Cities
Colette Bos – Nationale Wetenschapsagenda: Smart Liveable Cities
Ben-Willem Boswijk – Gemeente Zaanstad: Smart Liveable Cities
ir. **Willem Böttger** – Centre of Expertise Bio-Based Economy: LHP2016 Bio Based Bridge
Jacky Bourgeois: City of Things – Hackathon
ir. **Jan-Paul Boutkan** – Gemeente Enschede: LHP2015 RFID Sensors
Bouwend Nederland: De Toekomst Wordt Gebouwd
Aat Brand – Gemeente Rotterdam: Smart Liveable Cities
Lea den Broeder – Hogeschool van Amsterdam: Smart Liveable Cities
Eric Broekhuizen – Startupbootcamp: Future Formats for Applied Research
ing. **Ron Brons** – Nieuwenhuis Groep: LHP2014 Impenetrable Infiltration
Arno Bronswijk – ABB BV: PDENG Transition Towards DC Mirco Grids
Willem Buunk – Windesheim: Smart Liveable Cities
C2CA EU-Project: LHP2014 Robotically Driven Construction of Buildings
Sommer Cade – University of Kentucky: City of Things – Hackathon
Lenneart van Capelleveen – Ector Hoogstad Architecten: Real Additive Manufacturing: Prototype l Production
Cementbouw: LHP2016 CAST Formwork System
Ina Cheibas – Actual Build BV: R2R 3D-Printing in the Circular City
Bart Chompff – UNStudio: City of Realities
City of Rotterdam: Research to Reality
ClimateKIC: R2R Facade Leasing
Tom Commandeur: City of Things – Hackathon
Concrete Valley: Real Additive Manufacturing: 3D Concrete Printing
Jochem Cooiman – Gemeente Rotterdam: Smart Liveable Cities
CRH: Real Additive Manufacturing: 3D Concrete Printing
CyBe: Real Additive Manufacturing: 3D Concrete Printing
Kees d'Huy MSc. – TNO: Smart Liveable Cities
Anneke Dalhuisen – Heijmans NV: PDENG A Living Lab
Joop ten Dam – Windesheim: Smart Liveable Cities
DeHaan Westerhoff: R2R Facade Leasing
Dennis Dekker – Erfgoed 's-Hertogenbosch: City of Realities
Delft Robotics Institute (DRI): LHP2014 Robotically Driven Construction of Buildings
Angela Dellebeke – National Archives: LHP2017 Re-Printing Architectural Heritage
Martin Dennemark: City of Things – Hackathon
Carolien Dieleman – Hogeschool Rotterdam: Smart Liveable Cities
Stephan van Dijk – AMS Institute: Smart Liveable Cities
Romanos Dodopoulos – Volunteer Amsterdam: LHP2015 Saving Energy Battle
Balasz Dukai: City of Things – Hackathon
Jephta Dullaart – Het Erfgoedkabinet: City of Realities
Tom van Eck – Bouwend Nederland: Built Society Smart Reality, Smart Liveable Cities
ECOnnect: LHP2015 PD Lab
Ivan Elias Oliveira – Videohero: LHP2015 Saving Energy Battle
dr.ir. **Michael Emmerich** – Leiden University: R2R Excellent Building Performance
Charlotte van Emstede – Onderzoeksstudio CE: City of Realities
EPM BV: PDENG Transition Towards DC Mirco Grids

Dick Erinkveld – SolidRocks: LHP2014 Kine-Mould
Gaspard Estourgie – West8 urban design & Landscape architecture: GEVEL2016 Real Additive Manufacturing Workshop
EURECAT: LHP2016 Fibrous Smart Materials
Nico Eurelings: de Reus van Schimmert
Franca Eurlings-Tonnaer – Volunteer Rotterdam: LHP2015 Saving Energy Battle
Rik Eweg – Hogeschool Van Hall Larenstein: Smart Liveable Cities
Fabrication Factory: LHP2015 PD Lab
Simon Griffioen: City of Things – Hackathon
Festool Group GmbH & Co: LHP2015 PD Lab
Salome Galjaard – Arup: Real Additive Manufacturing: Real | Dream
Stephen Galsworthy – Quby: Research to Reality
Gemeenschappelijk Havenbeheer Twentekanalen: PDENG A Sustainable Life-cycle Method
Gemeente Rotterdam – Kabels en Leidingenbureau: LHP2017 ExcaSafeZone
C.P.W. Geurts – TNO: R2R Exploration of Building Integrated Photovoltaics
Bereddin Ghazal – QELP: City of Realities
Richard Giesen – Cementbouw: Research to Reality
Globld: PDENG Geometric Information Generator
GreenVillage: LHP2016 CAST Formwork System
Guardian Glass: LHP2015 PD Lab
Jordi Guasch Lopez – ESADE Business & Law School: PDENG A Living Lab
Maria Hänsch – SBRCURnet: Research to Reality
Chiel Harmse – Twentse Weg en Waterbouw: LHP2015 RFID Sensors
HECO-Schrauben GmbH & Co: LHP2015 PD Lab
Roland van der Heijden – Gemeente Rotterdam: LHP2015 Saving Energy Battle
Dave van der Helm – Atriensis: LHP2015 Saving Energy Battle
Rob Henderson – UNStudio: Research to Reality
dr. **Conrad Heinz Philipp** – University of South Australia: R2R Adapting to Future Climate Through Land Use
Jaap van den Herik – Leiden Centre of Data Science: Smart Liveable Cities
Harry Hermans – Volunteer The Hague: LHP2015 Saving Energy Battle
Kees Hermans – Volunteer The Hague: LHP2015 Saving Energy Battle
ir. **J. van den Heuvel** – De Twee Snoeken: PDENG Sustainable Performance Optimization
René Heuvelink – Volunteer Rotterdam: LHP2015 Saving Energy Battle
Virpi Heybroek – AMS-Institute: R2R 3D-Printing in the Circular City
Gaudi Hoedaya – Gaudi Hoedaya Design: City of Realities
Maarten Hommelberg – Harmon-E / BredeStroomversnelling: Research to Reality
ir. **Alwin Hoogendoorn** – Centre of Expertise Bio-Based Economy: LHP2016 Bio Based Bridge
Remko Huzen – Volunteer Rotterdam: LHP2015 Saving Energy Battle
HZ University of Applied Sciences: LHP2016 Bio Based Bridge
Isovlas Oisterwijk BV: LHP2015 PD Lab
Majorie Jans – De Bouwcampus: Built Society Smart Reality
Micah Johnson – University of Kentucky - College of Design: City of Realities
Jongeneel: LHP2016 CAST Formwork System
Pim Katelaars – Heijmans N.V. : PDENG A Living Lab
Duygu Kaynak: City of Things – Hackathon
Wim Kievits – Kievits Heritage & Management Cons.: City of Realities
Kindow: R2R Facade Leasing
Maurice de Kleijn – Spatial Information Laboratory (SPINlab) - VU University Amsterdam: City of Realities
Arjan Klem – Octatube: GEVEL2016 Real Additive Manufacturing Workshop
Jeroen Kluck – Hogeschool van Amsterdam: Smart Liveable Cities
Ramon Knoester – WHIM Architecture: Future Formats for Applied Research
Patrick Koimans – Bouwend Nederland: Built Society Smart Reality, Smart Liveable Cities
Reineke van der Kolk – Airbus Defense & Space: Smart Liveable Cities
Olaf van Kooten – INHolland: Smart Liveable Cities
Iris Korthagen – Rathenau Instituut: Smart Liveable Cities
Cint Kortmann – Quantbase: Smart Liveable Cities
Frank Kresin – Waag Society: Smart Liveable Cities
Alma Krug – Heijmans Technology : PDENG Luminescent Solar Concentrator
Alida van Krugten – Volunteer The Hague: LHP2015 Saving Energy Battle
Gert Kruithof – ASTRON: Smart Liveable Cities
Rogier Kuin – BOVAG: Smart Liveable Cities
Monique Lacroix – Rijksdienst voor Ondernemend Nederland: LHP2015 Saving Energy Battle
Michiel de Lange – Universiteit Utrecht: Smart Liveable Cities
Norman Langelaan – Monunumentenrestauratie-advies: City of Realities
prof. **Jiyong Lee** – Southern Illinois University, School of Art and Design: LHP2017 Re3 Glass
Gerard de Leede – Heijmans N.V. : PDENG A Living Lab
Thomas Leenders – Philips: Smart Liveable Cities
Marcus van Leeuwen – NWO: Smart Liveable Cities
Thed van Leeuwen – Universiteit Leiden: Smart Liveable Cities
Stephanie Leinders – Volunteer Rotterdam: LHP2015 Saving Energy Battle
ir. **Mark Lepelaar** – NPSP BV: LHP2016 Bio Based Bridge
Ferry Lochtenveld – Asfalt Centrale Hengelo: LHP2015 RFID Sensors
Betty Lou Pacey – BL Innovative Lighting - Vancouver: LHP2014 Energy Efficient Facade Lighting
Eric Lowe – University of Kentucky: City of Things – Hackathon
Marije Lutgendorff – Crowdlokaal: Future Formats for Applied Research
Maasstad Hout & Plaat bv: LHP2015 PD Lab
Kees Machielse – Hogeschool Rotterdam: Smart Liveable Cities
Hella Maessen – Atriensis: LHP2015 Saving Energy Battle
Stan Majoor – Hogeschool van Amsterdam: Smart Liveable Cities
Saeed Masroor – Volunteer The Hague: LHP2015 Saving Energy Battle
Thomas Mathew – Volunteer Amsterdam: LHP2015 Saving Energy Battle
Mebin (HeidelbergCement): LHP2014 Robotically Driven Construction of Buildings
Hayo Meijs – TBI Kennislab: LHP2016 Unleash the Building Bots
Judi Mesman – Universiteit Leiden: Smart Liveable Cities
Sadie Meyer – University of Kentucky: City of Things – Hackathon
MHZ: R2R Facade Leasing
Microsoft Netherlands: LHP2014 Semantic Web of Building Information
Puck Middelkoop MSc. – White Lioness technologies: LHP2016 Optimising 3D Concrete Printing
Frank Migchielsen – De Laurenskerk Rotterdam: LHP2016 Sound Absorbing Glass
Hans-Jaap Moes – Socrates: Research to Reality
dr. ir. **Mohamad Mohajeri** – Boskalis BV: LHP2016 Smart Sensors in Asphalt
Rishi Mohan – Volunteer Amsterdam: LHP2015 Saving Energy Battle
Alamir Mohsen – TU Darmstadt: Real Additive Manufacturing: Real | Dream
Gerben Mol – Wageningen University and Research: Smart Liveable Cities
Bart Molendijk – Katapult: City of Realities
Municipality of Rotterdam: LHP2016 Spying the Underground
Sander Mutsaards – BeemFlights: LHP2015 Throw in the I-drone
Rowan, de Nijs – Volunteer Rotterdam: LHP2015 Saving Energy Battle
ir. **K. Nix** – De Twee Snoeken: PDENG Sustainable Performance Optimization
Marieke van Nood – AEB Amsterdam: R2R 3D-Printing in the Circular City
Hans Nouwens – Smart Data City: Smart Liveable Cities
NWO: R2R Exploration of Building Integrated Photovoltaics, R2R Noise in Open-plan Study Environments
Erwin Onderdijk – STW: Smart Liveable Cities
Kay Oosterman – Zwarts & Jansma Architecten: Future Formats for Applied Research
Marco Oosterveld – BAM Wegen: LHP2015 RFID Sensors

Wim Oostveen – 3M Netherlands: LHP2017 Re-Printing Architectural Heritage
Richard van Os – Uppig Identity Store: City of Realities
dr. **Ad den Otter** – Stichting OPTI-School: PDENG Healthy Learning Environment
dr. **Henriette Otter** – Deltares: Smart Liveable Cities
Panelen Holland: R2R Facade Leasing
PARK4ALL b.v.: LHP2015 PD Lab
Wil Paulus – NEBER: PDENG Transition Towards DC Mirco Grids
Gert-Joost Peek – Hogeschool Rotterdam: Smart Liveable Cities
Ravi Peters: City of Things – Hackathon
Wibke Plagmann: City of Realities
POESIA: LHP2016 Restorative Glass
Poly-Ned: LHP2015 PD Lab
ProRail: R2R Fatigue Partial Factors for Bridges
Dennis Ramondt – Eneco: City of Things, Research to Reality
Joep Rats – Bouwend Nederland: Built Society Smart Reality
Real Capital Systems: R2R Facade Leasing
Recognize: LHP2016 Spying the Underground
Martha Regis – Volunteer Amsterdam: LHP2015 Saving Energy Battle
Olav Reijers – The Missing Link: City of Realities
Maarten Reiling – Gemeente Den Haag: City of Realities
Albert Reinstra – Cultural Heritage Agency of the Netherlands: LHP2017 Re-Printing Architectural Heritage
Renson: R2R Facade Leasing
Reynobond Alcoa Architectural Products: LHP2015 PD Lab
Samaneh Rezvani – 123DV architecten Rotterdam: Research to Reality, R2R Syntactic and/or Configraphic
Rijkswaterstaat: R2R Fatigue Partial Factors for Bridges
Riset 8 kota Indonesia: LHP2016 CAST Formwork System
Rojo Steigers: LHP2015 PD Lab
Rollecate bv: LHP2015 PD Lab
ir. **Anke Rolvink** – White Lioness technologies: LHP2016 Optimising 3D Concrete Printing
Jasper Roodenburg – NWO: Smart Liveable Cities
Carlien Roodink – Consultancy Carlien Roodink: Research to Reality
Ronald Root – Eneco: City of Things, Research to Reality
R. Rovers – Zuyd University of Applied Sciences: R2R Exploration of Building Integrated Photovoltaics
Sebastiaan van Ruitenbeek – Volunteer The Hague: LHP2015 Saving Energy Battle
Katherine Rutecki – Southern Illinois University, School of Art and Design: LHP2017 Re3 Glass
Frits Rutten – Stichting Bedrijventerrein Helmond: PDENG Industrial Symbiosis Software
Perica Savanovic – SBRCURnet: Research to Reality
Noor Schellens – Eco Klima BV: PDENG Healthy Learning Environment
Karen Schenk – Gemeente Haarlem: City of Realities
Scheuten: R2R Facade Leasing
Dick Schmidt – TNO: Smart Liveable Cities
Schuurman Elektrokern Solutions: R2R Facade Leasing
dr. **Gennaro Senatore** – Swiss Federal Institute of Technology: LHP2017 Adaptive Joints with Variable Stiffness
SGS Intron: Real Additive Manufacturing: 3D Concrete Printing
Haydee Sheombar – Kankan Tree: Research to Reality
Liana Sjerps-Koomen – TKI Urban Energy: Smart Liveable Cities
mr. **Berwich Sluer** – Boskalis BV: LHP2016 Smart Sensors in Asphalt
Vincent Smit – Vereniging Hogescholen / Haagse Hogeschool: Smart Liveable Cities
John Snippert – Twentse Weg en Waterbouw: LHP2015 RFID Sensors
Hannaneh Sobhani – Volunteer Amsterdam: LHP2015 Saving Energy Battle
SOMA College Harderwijk: LHP2017 ExcaSafeZone
Somfy: R2R Facade Leasing
Commandant **Peter van Sorgen** – Koninklijke Landmacht: LHP2016 Public Space for Refugees
SPARK: LHP2016 Bio Based Bridge
Jeroen van der Spiegel – Asfalt Centrale Hengelo: LHP2015 RFID Sensors
Kamiel Spoelstra – NIOO-KNAW: Smart Liveable Cities
Marthe Stallenberg – gemeente Den Haag: City of Realities
Marjanne Statema – MSTATEMA Erfgoed: City of Realities
Paula Stemkens – Volunteer The Hague: LHP2015 Saving Energy Battle
Stichting SKKB: Real Additive Manufacturing: 3D Concrete Printing
Harry Stokman – DC Flexhouse: PDENG Transition Towards DC Mirco Grids
Anna Stolyarova – Street Art Museum Amsterdam: City of Realities
Sandra Storm – Vereniging Hogescholen: Smart Liveable Cities
Holger Strauss – Emmer Pfenninger Partner AG: Real Additive Manufacturing: Prototype | Production
StudioRAP: LHP2014 Robotically Driven Construction of Buildings
STW: R2R Excellent Building Performance
Trevor Tanzi – University of Kentucky - College of Design: City of Realities
Emily Taylor – University of Kentucky - College of Design: City of Realities
Technobis: LHP2016 Smart Sensors in Asphalt
Ron Teeuw – BLOMSMA PRINT&SIGN: LHP2017 Reprinting Architectural Heritage
Rik Tersteeg – Arup: City of Realities
Oliver Tessmann – TU Darmstadt: Real Additive Manufacturing: Real | Dream
The New Makers: LHP2015 PD Lab
Ernst Thijsen – Height-Tech Benelux B.V.: LHP2015 Throw in the I-drone
Loes Thijssen – NOAHH: City of Realities
Dick Timmermans – Heijmans N.V. : PDENG A Living Lab
TNO: R2R Fatigue Partial Factors for Bridges
Alice Tonnaer – Volunteer Rotterdam: LHP2015 Saving Energy Battle
Frans Tonnaer – Volunteer Rotterdam: LHP2015 Saving Energy Battle
Marie-Louise Tonnaer-Hoenen – Volunteer Rotterdam: LHP2015 Saving Energy Battle
Trox: R2R Facade Leasing
Laura Ubachs – NOV'82 Architecten: City of Realities
Ilonca Vaartjes – Universitair Medisch Centrum Utrecht: Smart Liveable Cities
Van Gelder: LHP2016 CAST Formwork System
Van Wijnen: Real Additive Manufacturing: 3D Concrete Printing
Valentin Vanhecke – 4Visualization: LHP2017 Reprinting Architectural Heritage
Dave Vanhove – 3D idea printing: LHP2017 Reprinting Architectural Heritage
Nuno Varandas: City of Things
Peter Paul van 't Veen – TNO: Smart Liveable Cities
Diederik Veenendaal – Summum / Block Research Group ETH Zürich: Research to Reality
ing. **Alex Veldhoff** – Selekthuis Bouwgroep: LHP2014 Impenetrable Infiltration
Richard Verbruggen – Van nut: LHP2015 Saving Energy Battle
Verhoeven Timmerfabriek: Real Additive Manufacturing: 3D Concrete Printing
Teun Verkerk – Science Center Delft: City of Things
Stijn Verkuilen – Heijmans Technology : PDENG Luminescent Solar Concentrator
Vanessa Vidal Ladera – University of Kentucky - College of Design: City of Realities
Marcel Visser – NIOO-KNAW: Smart Liveable Cities
ing. **Rienk Visser** – Lighting designer: LHP2014 Energy Efficient Facade Lighting
Cindy Vissering – SBRCURnet: Research to Reality
Dick Vlasblom – QUBICX: LHP2016 SPONG3D, GEVEL2016 Real Additive Manufacturing Workshop, LHP2017 Re-Printing Architectural Heritage, Research to Reality
Harry Vleems – VleemsConnections: City of Realities
VML Technologies: R2R Facade Leasing
Monique Volman – Universiteit van Amsterdam: Smart Liveable Cities
Z.A.E.P. Vroon – Zuyd University of Applied Sciences: R2R Exploration of Building

Damien Vurpillot – Spatial Information Laboratory (SPINlab) - VU University Amsterdam: City of Realities
Peter van Waart – Hogeschool Rotterdam: Smart Liveable Cities
Guido Walraven – INHolland: Smart Liveable Cities
Hein van der Water – SiO2 glas: LHP2016 Sound Absorbing Glass
Weber Beamix: Real Additive Manufacturing: 3D Concrete Printing
Bill Wei – Rijkdienst van Cultureel Erfgoed: LHP2015 Saving Energy Battle
Karin Westerink – Gemeente Amsterdam: LHP2015 Saving Energy Battle
Ruud van Wezel – Haagse Hogeschool: Smart Liveable Cities
ir. **A. Wijnen** – De Twee Snoeken: PDENG Sustainable Performance Optimization
Sabine Wildevuur – Waag Society: Smart Liveable Cities
Pepijn van Wiligenburg – Direct Current BV: PDENG Transition Towards DC Mirco Grids
Esther Willems – Volunteer Rotterdam: LHP2015 Saving Energy Battle
Ferdie van de Winkel – Stichting OPTI-School: PDENG Healthy Learning Environment
Martine de Wit – Actual Build BV: R2R 3D-Printing in the Circular City
Witteveen+Bos: Real Additive Manufacturing: 3D Concrete Printing
mr. **Frans van Zeeland** – Municipality of Laarbeek: LHP2015 Leafroof
Dr.-Ing. **Gregor Zimmermann** – G.tecz: LHP2016 Convective Concrete, Real Additive Manufacturing: Real | Dream
Liesbet van Zoonen – Erasmus Universiteit Rotterdam: Smart Liveable Cities

ORGANISATION 2014 – 2017

prof.Dr.-Ing **Ulrich Knaack** – Delft University of Technology:
scientific director
ir. **Alexander Schmets** – Delft University of Technology:
executive director
ir. **Siebe Bakker** – bureaubakker:
curator

Ambassadors

prof.dr.ir.ing. **André Dorée** – University of Twente (scientific director 2018 >)
dr.ir. **Frank van der Hoeven** – Delft University of Technology
prof.dr.ir. **Erik Schlangen** – Delft University of Technology
prof.dr.ir. **Bauke de Vries** – Eindhoven University of Technology

Deans

prof.dr. **Geert Dewulf** - University of Twente - Dean Engineering Technology
prof.dr.ir. **Bert Geerken** – Delft University of Technology, Dean Civil Engineering and Geosciences
prof.ir. **Elphi Nelissen** – Eindhoven University of Technology, Dean Built Environment
prof. **Peter Russell** – Delft University of Technology, Dean Architecture and the Built Environment

Supported by

Elise Buiter MSc. – bureaubakker: City of Realities, City of Things, Real Additive Manufacturing: Prototype | Production, Research to Reality, 'Newspaper' 2016, Infratech 2017, Bouwbeurs 2017
Kim Degen MSc. – bureaubakker: City of Things
Kyra Galjee MSc. – bureaubakker: Research to Reality
ir. **Patricia Hessing** – Ateliers: City of Realities
Anna Karina Janssen MSc. – bureaubakker: Week van de Bouw 2015, 'Newspaper' 2014
Dré Kampfraath – creative projects: City of Realities, City of Things, Future Formats for Applied Research, Infographics 2015 – 2017, Research to Reality
Ad van der Kouwe – Manifesta: Infograhics LHP2014
Lisa Kuijpers – Delft University of Technology: De Toekomst Wordt Gebouwd
Soscha Monteiro de Jesus MSc. – bureaubakker: Research to Reality book
Mariet Sauerwein MSc. – bureaubakker: City of Things, 'Newspaper' 2015, GEVEL2016
Frans Schupp – Frans Schupp Grafisch Ontwerp: City of Things, Infographics 2015 – 2017
ir. **Jasper Westebring** – Ateliers: City of Realities

4TU.Bouw
center of excellence for the built environment

TU Delft Delft University of Technology

TU/e Technische Universiteit Eindhoven University of Technology

UNIVERSITY OF TWENTE.

WAGENINGEN UNIVERSITY & RESEARCH

RESEARCH TO REALITY

4TU.Bouw 2014 – 2017

4TU.Bouw is the collaboration between the built environment related faculties of the four technical universities in the Netherlands: Delft University of Technology, Eindhoven University of Technology, University of Twente and Wageningen University & Research.

Future challenges for the built environment, like scarcity of resources, climate change, accelerated population growth and demographic change, demand for joint strategies and action. 4TU.Bouw aims to promote collaboration between the universities, industrial partners and the government, in order to meet these grand challenges ahead.

This book presents an overview of the four-year period from 2014 to 2017. Around 350 researchers and students from the faculties affiliated with 4TU.bouw, worked with at least 300 experts from other faculties, industries, market parties and governments on a range of collaborative research projects, match-making events, and investigative workshops and conferences. Four years of 4TU.Bouw, led by Scientific Director Ulrich Knaack.

4TU.Bouw
center of excellence for the built environment

9 789463 661041 >