4TU.Bouw represents the collaboration between the four Technical Universities in the Netherlands on the large topic of “The Built Environment.” The cooperation consists of the Department of the Built Environment at Eindhoven University of Technology, the 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. The goal of the 4TU.Bouw initiative is to promote collaboration between the member faculties, industrial partners and government, in order to meet the grand challenges ahead.

Built Environment is the biotope of the modern citizen, providing infrastructure for transport, defense against flooding, shelter, space for working, meeting and leisure activities, etc. The demands upon reliability, safety and comfort of these structures are continuously increasing. Meanwhile the Built Environment sector is confronted with enormous challenges like scarcity of resources, climate change, accelerated population growth and demographic changes. These challenges require joint strategies and collaboration between end-user, academia, the industry and governmental agencies, the so-called golden triangle.

Therefore, in the context of the Dutch “Nationale Wetenschapsagenda”, 4TU.Bouw, with its partners, has identified the important, societal and scientifically relevant research themes: “De Toekomst Wordt Gebouwd”, as well as the “Built Society Smart Reality” urgency and ambition “Map”. Relevant themes have been utilized as context for the 4TU.Bouw Lighthouse programmes 2016 and 2017. In 2017 eight dedicated, fast track innovation projects have been completed, all addressing aspects of the agenda and map. These projects provide a proof of concept – or failure – of new technologies that will contribute to solid approaches and solutions to the challenges ahead, for all stakeholders.

Also, a dedicated PDEng-training programme contributes to the future availability of well-trained specialists, meanwhile bridging the gap between academia and the market. 4TU.Bouw strives to respond rapidly to the ever faster changes, often emerging bottom-up, that new technologies bring about, by organizing workshops, brainstorms and training sessions with relevant stakeholders, and by forming dedicated consortia that act jointly. Only by such joint actions with respect to the urgent themes are positive changes expected to happen.

Scientific Director – Ulrich Knaack (2014 - 2017), André Dorée (2018 onwards); Executive Director – Alexander Schmets; Curator – Siebe Bakker

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.

INFO & CONTACT

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PUBLICATION

Editing & graphic design: bureaubakker – Siebe Bakker

Images: bureaubakker, creative projects (pp: 6, 8, 10, 12, 14, 16, 20, 22, 24, 28 – 31), participating researchers

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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 have been developed is extremely promising. The addition of steel fibers to concrete to replace conventional reinforcement bars or to increase the ductility of the material has yet been able to produce additively manufactured concrete with 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.

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.

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 ofductility (andflexural) tensile strength that could be obtained 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 to increase the ductility of the material has yet been able to produce additively manufactured concrete with the required structural performance. After an intense trajectory of fine-tuning the material properties, two printable mix designs [Figure 3] were obtained that both showed clear increase in flexural strength was nevertheless achieved (Figure 1). The fiber orientation was achieved (Figure 1). The fiber orientation was achieved (Figure 1). The fiber orientation was achieved (Figure 1). The fiber orientation was achieved (Figure 1). The fiber orientation was achieved (Figure 1). The fiber orientation was achieved (Figure 1). The fiber orientation was achieved (Figure 1). The fiber orientation was achieved (Figure 1).

Steel Cable Reinforced 3D Printed Concrete

A completely different approach is to retrofit the conventional reinforcement bars and apply highly flexible high strength steel cables instead. A device was developed to entwine 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. Entwining 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 (Figure 7). 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.
The environment around buildings keeps changing, while the static design solutions of buildings cannot perform well during the whole service life. In order to improve structural performance including strength (i.e. avoid collapse) and servability, adaptive structures are likely to establish as one of future trends in both research and application for the built environment.

This project aims to synthesize a type of structural joints with variable stiffness capabilities. Stiffness variation is achieved by strategically arranged materials with transduction properties. Shape memory polymers (SMPs) feature large variation of stiffness between a glassy and a rubbery state, which makes them good candidates for application in shape control of adaptive structures. The structures will change themselves into optimal shapes corresponding to different load conditions. However, large shape changes require significant flexibility of the joints because their fixity can affect load-path and shape control. To address this problem, a variable stiffness joint is proposed. During shape/load-path control, the joint reduces its stiffness so that required deformation patterns can be achieved with low actuation energy. After shape control the joint recovers rigidity. In this way, stiffness variation is feasible but control intelligence and actuators are required.

Large shape changes are employed as a structural adaptation strategy to counteract the effect of an external load. The structure is designed to ‘morph’ into optimal shapes as the load changes. This way the stress can be homogenized, avoiding peak demands that occur rarely. As a result, stability can be improved and the ultimate strength can be substantially increased. However, large shape changes require significant flexibility of the joints because their fixity can affect load-path and shape control. To address this problem, a variable stiffness joint is proposed. During shape/load-path control, the joint reduces its stiffness so that required deformation patterns can be achieved with low actuation energy. After shape control the joint recovers rigidity. In this way, stiffness variation is feasible but control intelligence and actuators are required.

Structural design and control strategy

Conventional structural design solutions relying on passive technologies have limited capabilities against large changes in the external environment. Adaptive structures are defined as structures capable of actively countering the effect of external loads via controlled shape changes and redirection of the internal load path. These structures are integrated with sensors (e.g. strain, vision), control intelligence and actuators. This project investigates the use of variable stiffness joints in adaptive structures to achieve large shape changes. Large shape changes are employed as a structural adaptation strategy to counteract the effect of an external load. The structure is designed to ‘morph’ into optimal shapes as the load changes. This way the stress can be homogenized, avoiding peak demands that occur rarely. As a result, stability can be improved and the ultimate strength can be substantially increased. However, large shape changes require significant flexibility of the joints because their fixity can affect load-path and shape control. To address this problem, a variable stiffness joint is proposed. During shape/load-path control, the joint reduces its stiffness so that required deformation patterns can be achieved with low actuation energy. After shape control the joint recovers rigidity. In this way, stiffness variation is feasible but control intelligence and actuators are required.

Problem statement

However, large shape changes require significant flexibility of the joints because their fixity can affect load-path and shape control. To address this problem, a variable stiffness joint is proposed. During shape/load-path control, the joint reduces its stiffness so that required deformation patterns can be achieved with low actuation energy. After shape control the joint recovers rigidity. In this way, stiffness variation is feasible but control accuracy can be increased.

Possible material solution - SMP

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 – SMP joints

1:6 scaled prototypes with respect to the joint dimensions in a 2D plane arch truss was fabricated via fused deposition modelling. SMP filaments were used as raw material. The joints are designed to be easily connected to tubular and plate-shaped elements. SMP joints have been developed. Resistive heating is used as SMP actuation method. Different patterns have been tested using one continuous heating wire which is connected to a simple 20Ω heater. A pattern made of 2-mm diameter through holes allows a 3-mm diameter tubes to penetrate the SMP joint. Heating wire to go through the depth of the joint as well as its width. Two thermocouples monitor the temperature of the surface and the heating wire, while a RTD temperature gives the feedback to a temperature controller. It is recorded that around 35s after heating, stiffness variation was feasible but the carbon fibre caused a short circuit. Therefore, isolation is required to avoid this problem or alternatively use only Kevlar as reinforcement skin.

Future work – full scale SMP joints

The use of variable stiffness joints in adaptive structures has the potential for reducing actuation work during structural adaptation. Experimental tests show that joint stiffness variation to deal with quasi-static load is feasible. Future work will investigate feasibility of a full scale fiber reinforced SMP joint on a simple 4-element frame. The structure will be designed to withstand a load of 10kN applied on the joint in several directions. Practically the load will be applied by a person interacting with the structure, which will result by changing shape.
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 threat 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 streamline 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 existing 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 (H2C). 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) who 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 respondents 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 workshops revealed that practitioners judge safety and project risks by using objects on various levels of granularity. 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 to risk. As a next step, the team further consulted what existing open data sources could be used to gain a richer set of information about the objects on the excavation site. Next, they analyzed the context, 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 Hooigracht 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 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 site.

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 ~5 points). We visualized these risks in our web-based heat map prototype to integrate risk-related objects on the selected construction site (radiodensity, 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 H2C and apply it in a 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.
Main results and recommendation
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 MSc lab 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 calculating its geopolymer reinforced concrete element and as input for the structural design of the geopolymer bridge.

Up-scaling and structural application
The current design codes for concrete structures are based on compressive strength (concrete Clark 1983) 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 behavior of the reinforced elements over time had to be known. The flexural behavior (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 showed that the structural performance 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 the reduced stiffness, reinforced AAC beams show larger deflections and exhibit a more ductile behavior (higher rotational capacity) compared to reinforced OPC concrete, which is consistent with results reported by Shah & Shah (2017). 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 pre-stressed geopolymer bridge, where benefits of fast hardening can also be utilized, 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 are 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 4 m. The total height is chosen equal to 250 mm (see Figure 7). The mechanical properties of geopolymer concrete were taken from the optimized mixture. The required amount of reinforcement was calculated and it seems practical. The deformations values 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 MSc lab had been done within the additional master thesis project of Zhekang Huang. The optimized mixture was also used in a geopolymer reinforced concrete (GRC) bench and beam. The bench has been placed in the street G.J. de Jonghweg, Rotterdam (Fig. 8 and news in https://www.rotterdam.nl/ nieuws/nieuwsbericht).
2. The work performed in the group of Concrete Structures was done within the MSc thesis project of Silke Prinsse.

Components: Optimized geopolymer concrete mixture S50

<table>
<thead>
<tr>
<th>Component</th>
<th>Optimized geopolymer concrete mixture S50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fly ash</td>
<td>200</td>
</tr>
<tr>
<td>Blast furnace slag</td>
<td>200</td>
</tr>
<tr>
<td>Aggregates (4-8 mm)</td>
<td>789.14</td>
</tr>
<tr>
<td>Aggregates (2-4 mm)</td>
<td>439.21</td>
</tr>
<tr>
<td>Aggregates (0-2 mm)</td>
<td>524.09</td>
</tr>
<tr>
<td>Alkaline activator</td>
<td>27.2</td>
</tr>
</tbody>
</table>

Table 1: Optimized concrete mixture design (kg/m³)

Fig.1 Slump test of optimized concrete mixture.

Fig.2 Compressive strength test results for optimized mixture.

Fig.3 Flexural strength test results for optimized mixture.

Fig.4 E-modulus and Poisson’s ratio.

Fig.5 Test set-up. Left: painted side of beam for image analysis. Right: control beam (that had similar E-modulus, but lower compressive strength).

Fig.6 Development of cracks during four-point bending tests on S50 beams at 12, 28 and 69 days and comparison with OPC concrete control beam. Results by Zhelong Huang. S50 specimen have been cured (OPC and OPC-HRM) for 28 days. After this, the creeps tests were exposed to laboratory conditions (OPC and OPC-HRM) until testing. OPC concrete was kept in the mould for 28 days (covered with plastic) at lab conditions and then unmoistened.
Research in consumer preferences

We performed a stated choice experiment among 480 participants of a Dutch national on-line panel in the age group of 50-79. Each respondent saw one of twelve randomly composed choice sets, consisting of two alternative dwellings each. The dwellings were specified as apartments sized between 72 m² and 170 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 100 m²;
- balcony 12 m²;
- open kitchen;
- medium size building with 20 to 80 dwellings;
- entrance through an outdoor gallery instead of a passage;
- 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.

Consumer toolbox and the best living concepts

The stated choice experiment allows to calculate the value elderly attach to the specific attributes of the dwelling, building and block. We translated these results into an easy to interpret consumer toolbox, see Figure 2 below. 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 follows. 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 well.

The consumer toolbox offers clear trade-offs between improving and worsening the levels of certain attributes. This 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 170 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 a passage; they all can be reached from inside each building. 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.

Parking can be realized on the ground level, especially in a corner of the block or in the middle of the block. In the former solution, the parking space 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. 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 space 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.

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 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.

The architectural toolbox offers construction elements that allow to adjust the design to a specific situation.
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 deposits the last judgement, and is part of a series of scenes made by Albrecht Dürer.

Throughout the process of scanning and printing the section, we encountered multiple challenges, both in the use of additive manufacturing technology to capture the existing cracks in the required resolution, to the high costs of specialty 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 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 detail of level we needed, requiring new scanning. As it was practically impossible to reach the required height with the scaffold, the project members took color pictures and made the required scans with the laser scanner from a 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 15x12 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 as a 3D printed structure with visible surface microstructures. In principle, the film print ought to take into account the cracks and a complex wall 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 object quality yet. We therefore opted to create a flexible thin foil layer (3D printing) 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.

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 object quality yet. We therefore opted to create a flexible thin foil layer (3D printing) and fix it over the 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.

Exploring Current 3D Printing and Scanning Technologies

The goal of the project, to be presented in March 2018, is to test the interpretation of the entire scanned vault structure through an additional matt layer.

The materiality of the findings of this study will lead to the production of a workshop entitled “Re-Printing Architectural Heritage,” which will bring together scholars from various fields to discuss the final outcomes of our research on the Hippolytus church and of a parallel project involving the Mauritshuis.
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 transmission and space continuity. The fabrication boundaries of the material are constantly stretching: visible metal connections are minimized and glass surfaces are maximized, resulting in pure 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 plane, 2D glass elements. Moreover, despite the fact that glass is fully recyclable, most of the glass currently employed in buildings is not necessarily recycled due to its perpixel disassembly and its contamination from coatings and adhesives.

Cast glass can be the answer to the above restrictions, 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, which can be further bonded to achieve solid monomaterial components of considerably larger cross-sections, which can be further bonded to achieve solid monomaterial components of planar, 2D glass elements. Moreover, despite the fact that glass is currently employed in buildings in respect to the waste hierarchy of embodied energy, the use of cast glass is proposed instead of common applied laminated float glass, which suggests an innovative and sustainable way of building with glass.

The new generation of REcyclable, REDucible and REUsable cast glass components, which suggests an innovative and sustainable way of building with glass.

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Lighthouse Projects Evaluation

Main Findings & Interview Summary

Notes
- Based on 46 respondents.
- All 36 Lighthouse Projects from 2014, 2015 and 2016 are represented.
- Most 2016 Lighthouse Projects do not yet show spin-off or impact, due to delivery time of results end of 2016.

Main Findings Interviews
- Lighthouse Projects are highly valued as additional type/format to other research funding.
- Positive assessment of collaboration with industry 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 LPF program (scientific, press, exhibitions, etc.).
- In relation to projects within other funding systems good score in terms of output volume, diversity and unique concepts.
- Spin-off with 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.

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 do 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 did 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?
  - 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 TUs?
- Did the collaboration lead to more information exchange?
- Did 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 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?

Main Findings Data Analysis
- 163 LHP applications (262 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 TUs collaborating, 15% 3 TUs collaborating.

Conclusions
- 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 definition of tangible results in call may attract wider range of idea.
- Budget availability aka "project hour" contracted staff is in high demand.
- More 'after-case' in relation to follow-ups with 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 PNO projects with a comparable total budget.
- Lighthouse Projects support organised by 4TU.Bouw (Infographics workshops) leads to similar support for other PhD and PDEng projects been 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.

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?
Further benefits of soil as a building material are highlighted. Today, in combination with innovative technologies it could be reconsidered and regain its relevance.

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. A low adaptability to location-based needs. As an outcome, low-quality temporary shelters are provided, which are often exceeded by for their serving time. Focusing on temporary shelters suitable for the transitioning period between emergency accommodation and permanent housing. TERRA-INK aims to develop 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 depositing the material in layers. Parallel to the 3D printing, a simple round-shaped prototype was used to study the mechanical performance of the material. The advantage of additive manufacturing is the potential for innovation in an emergency relief context. In fact, the shape and geometries of the shelter are a consequence of the printing process. During the deposition, the liquid material tends to spread and eventually settle under its own weight. When occurring in rather uncontrolled environments such as on-site, where shelters are usually organized and divided in separate phases. Each phase addresses different problems and needs. A temporary shelter is meant to respond to an immediate phase of the emergency, to facilitate the transition from emergency accommodations to more durable 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 display and dismantle.

Aiming to increase the flexibility and adaptability of the project, the team examined the potential of a construction system based on the composition of soil material, without relying on a specific technology or material recipe. However, rather adjusting to the available resources. During the project, the use of both local materials and off-the-shelf products was considered, in order to define how various natural materials and types can 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 (e.g. straw, jute and hemp) was confirmed to be an important aspect in the design of the mixture, as the fibers in the mix increase the tensile resistance of the soil and reduce the shrinkage.

Deserted building systems have the potential of combining low- and high-tech human labor, as well as 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 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 display and dismantle.

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Air curtain technology 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 require detailed knowledge of the relationship between the separation efficiency of air curtains—which is 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 performance of air curtains while giving special attention to the study of jet excitation techniques by means of optimizing the separation efficiency of air curtains.

The 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 their 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 (Choi 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 materials across the two environments. This separation aims to improve thermal comfort, air quality, energy efficiency and fire protection in buildings (Eklundh et al., 2017; Wang & Zhong, 2014).

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.

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 (Simmench & Pande, 1999). 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 (e.g., draft and air temperature differences) (Frank & Linder, 2014). Furthermore, air curtains are frequently used in other specialised 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 hazards in laboratories and hospital rooms (Zha & Osbome, 2013; Shi et al., 2011); for retaining the refrigeration properties of cold rooms and display cabinets (Zvirikie 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 curtain technologies. The project comprises the following goals:

1. Understanding the increase or reduction of heat and mass exchange through an air curtain when subjected to a variety of jet and environmental parameters.
2. Investigation of the influence of jet and structural features 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 (e.g., cross jet temperature, pressure and concentration variations), and parametrically investigate the effects of jet excitations on the jet and vortex characteristics by means of optimization of current air curtains. Furthermore, Jet Dynamics (CFD) are conducted to analyze the fundamental flow behavior, systematically evaluate the performance of air curtains under different operational settings and environmental conditions (e.g., cross jet temperature, pressure and concentration variations), and parametrically investigate the effects of jet excitations on the jet and vortex characteristics by means of optimization of current 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. 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/city pressure). 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:

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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. 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 can still make and how it effects 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 should be able to display how these wishes are met.

To expand WoonConnect, we first aim to add additional calculation methods to assess multiple criteria (e.g. CO2-emissions, material consumption or comfort). Within WoonConnect, the software will display an interface that will display which investments the user can still make and how it effects the performances of the building with regards to different criteria.

Expanding WoonConnect
To further develop this tool the aim is to integrate the following aspects within WoonConnect:
- The software should be able to display the existing building performances in terms of different (sustainable) criteria. The tool should display this in a way that it provides relevant information for the users.
- The software should be 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 should be 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 (maximum) potential of the building is to reach this goal.

Approach
WoonConnect in the current state uses an existing 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 users can already adjust these digital houses with different renovation options. These renovation options are mapped by de Twee Snoeken in cooperation with the users. 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.

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To expand WoonConnect, a digital tool that can help to speed up this transition for both renovation projects and new buildings.

Eindhoven University of Technology
Bauke de Vries
De Twee Snoeken

dr.ir. Randy van Eck

K. Nix, A. Wijnen, J. van den Heuvel
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 - were challenged to investigate 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 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.

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 order to support researchers in developing graphic representations of their projects, TU Eindhoven 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 filling in elements from details.

Each workshop starts with brief 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, shareability 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 to work 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.
Existing safety systems are:

- Not user friendly
- Not affordable

Why?

- Existing safety systems are:
  - Not affordable by third parties
  - Difficult to use for non-professional users

Challenge:

- Simple and cost-effective
- Low cost
- User-friendly
- Tailored to the excavation operation
- Compatible with the existing pipeline location data

Goal:

- Existing pipeline location data
- Compatibility with the existing pipeline location data

Develop a safety system which is:

- Mountable on excavator
- Tailored to the excavation operation
- False alarm rate
- Low cost

Which is:

- User-friendly
- Affordable by third parties

Results:

- Difficult to use for non-professional users
- Irreversible impact on historic buildings
- Damage to historic buildings
- No risk increase
- Historic buildings stay intact

Museum specifications:

20°C / 50% RH

Microclimate for cultural heritage

Museum specifications

20°C / 50% RH

Energy efficient cultural object, sustainable buildings

Modeling of energy conserving climate control strategies on indoor climate behavior

Total result of tolerant approach

Reduced number of false alarms

- 50% energy cost
- 50% of gas pipeline incidents
- 50% of gas pipeline incidents

Public procurement of innovation

- Request for solutions
- Request for new solutions
- Non-intrusive for excavation operation
- Improved strategies, legal and decision support for avoiding test trench locations

End result workshop session

End result workshop session

End result workshop session

End result workshop session

End result workshop session

End result workshop session