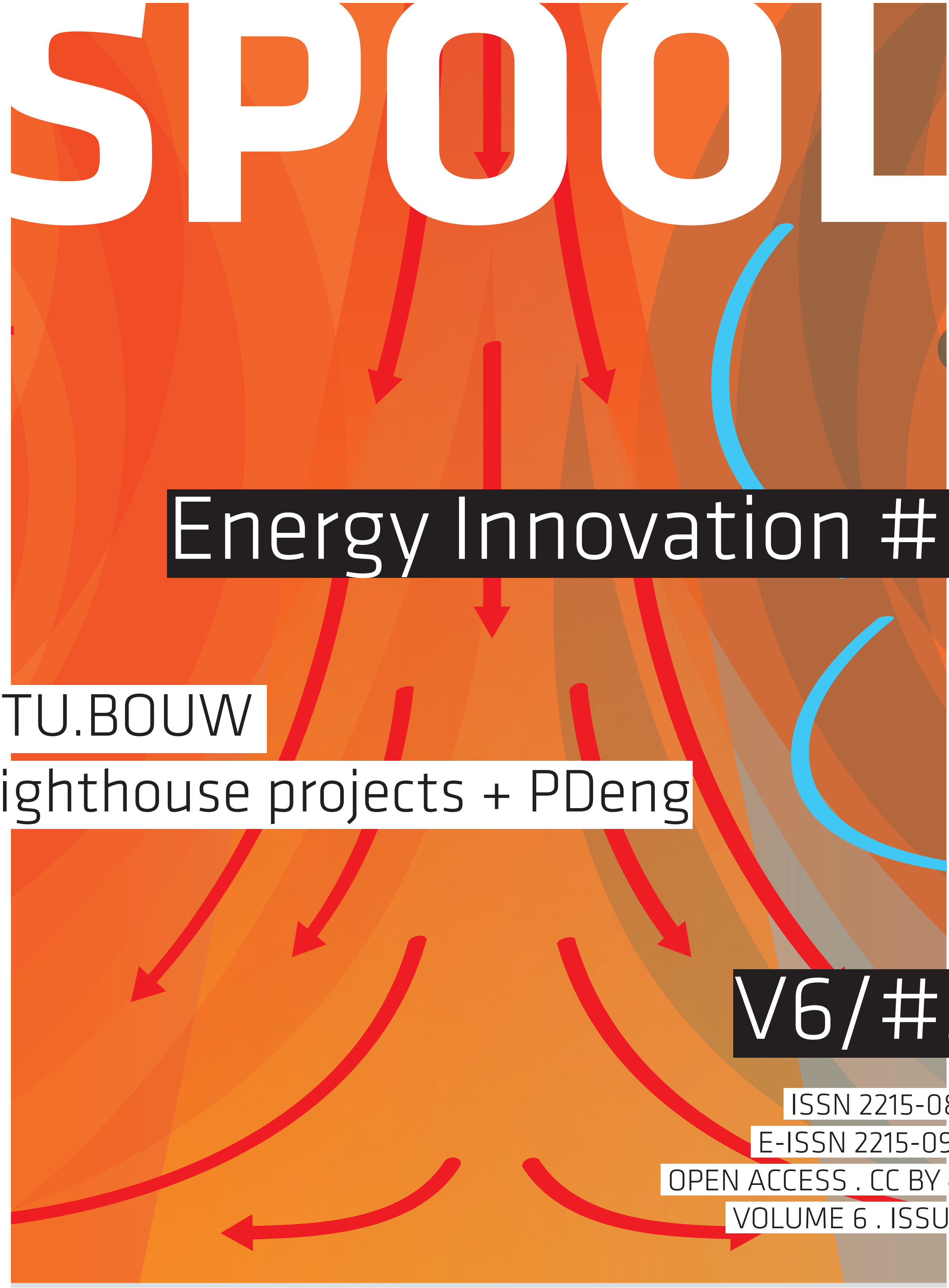


SPOOL

Energy Innovation #5

4TU.BOUW
Lighthouse projects + PDeng

V6/#2

ISSN 2215-0897
E-ISSN 2215-0900

VOLUME 6 . ISSUE 2

SPOOL

VOLUME 6 . ISSUE 2

Energy Innovation #5

Editorial

Projects

SPOOL - Journal of Architecture and the Built Environment

SPOOL is a journal initiative in the field of 'architecture and the built environment'. It puts a strong emphasis on four key topics: Science of Architecture; Landscape Metropolis; Energy Innovation and Cyber-physical Architecture. These four topics refer to existing and upcoming research programmes/interests in Europe and beyond, and ensure a steady stream of potential copy. Treating these topics as threads within one journal allows SPOOL to focus on the interrelationship between the fields, something that is often lost in specialised journals. SPOOL welcomes within this framework original papers and associated open data on research that deal with interventions in architecture and the built environment by means of design, engineering and/or planning.

ISBN
978-94-6366-246-8

Cover images
Front: air curtain optimization. Back: infographic workshop

Publisher
TU Delft Open, Faculty of Architecture and the Built Environment
Julianalaan 134, 2628 BL Delft, The Netherlands

Contact
Principal: Frank van der Hoeven (f.d.vanderhoeven@tudelft.nl)

Design
Sirene Ontwerpers, Rotterdam, NL

ISSN 2215-0897
E-ISSN 2215-0900

www.spool.tudelft.nl

EDITORIAL

4TU.Bouw Lighthouse projects + PDEng

Siebe Bakker, Frank van der Hoeven

Faculty of Architecture and the Built Environment
Delft University of Technology

Spool has published previously four issues dedicated to projects, developed in a high-risk innovation programme: the so-called the 4TU.BOUW lighthouse projects. Initially, the main topic of this programme was Energy-Innovation, hence the name of this “thread”. This issue of Spool presents the last batch of Lighthouse projects as the programme came to a close.

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 the Eindhoven University of Technology, the faculty of Engineering Technology at the University of Twente, the faculty of Architecture and the Built Environment and the faculty of 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, to meet the grand challenges ahead.

Built Environment is the biotope of the modern citizen, providing infrastructure for transport, defence against flooding, shelter, space for working, meeting and leisure activities. 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 critical, societal and scientifically relevant research themes: ‘De Toekomst Wordt Gebouwd’, as well as the ‘Built Society Smart Reality’ urgency and ambition ‘map’.

Relevant themes were used as a 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 contribute to reliable 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. Only by such joint actions concerning the urgent themes are positive changes expected to happen.

3D Concrete Printing for Structural Applications

Freek Bos [1], **Zeeshan Ahmed** [1], **Claudia Romero Rodriguez** [2], **Stefan Chaves Figueiredo** [2]

[1] *Eindhoven University of Technology*
[2] *Delft University of Technology*

Abstract

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.

Keywords

concrete, fiber, reinforcement, structural, methods

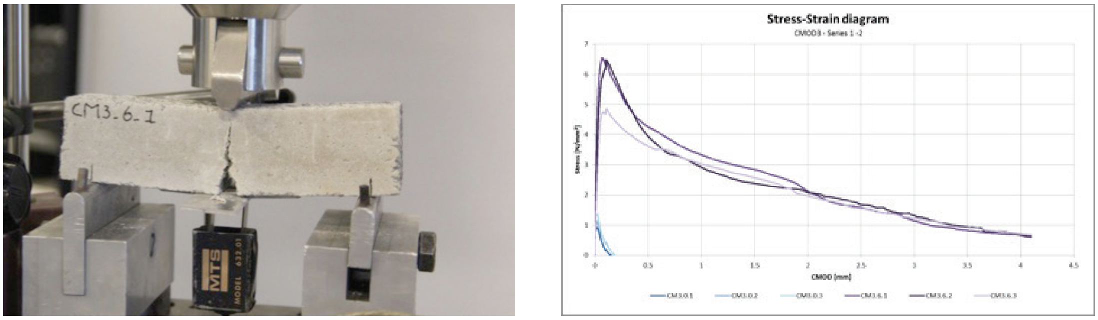
Introduction

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).

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



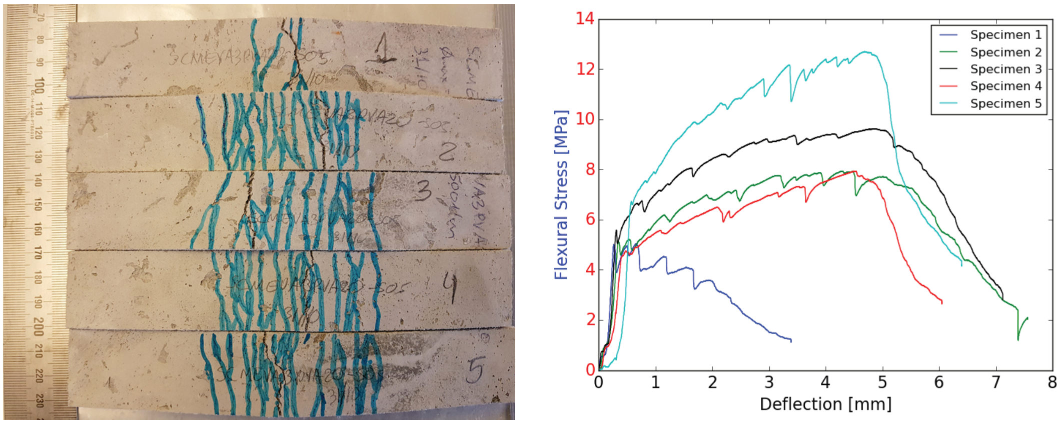
(a) *(b)*

FIGURE 2 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).

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.

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



(a) *(b)*

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

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 (Figure 7). Several hundred meters were applied.

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

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

FIGURE 7 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).

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.

Adaptive Variable Stiffness with Strategically Arranged Materials

Henriette Bier [1], **Arwin Hidding** [1], **Emma Chris Avramiea** [1]

[1] *Delft University of Technology*

Abstract

By designing materials with variable stiffness, structures can adapt to various functional requirements. This paper presents variable stiffness explored in two case studies relying on an architected material approach that involved gradient pattern differentiation and freeform printing using thermoplastic polymers (TPE). The differentiated cell pattern had gradients from high to low density of cells, which facilitate variable stiffness. Numerical and experimental studies showed the potential for application of materials with variable stiffness in adaptive structures.

Keywords

adaptive structure, robotic 3D printing, variable stiffness

Considering adaptive structures as being capable to respond dynamically to changing requirements by employing material design strategies that facilitate reconfiguration, two cases have been explored, in which reconfiguration is achieved by architecting the material using computational design and robotic 3D printing techniques (Fig. 1).

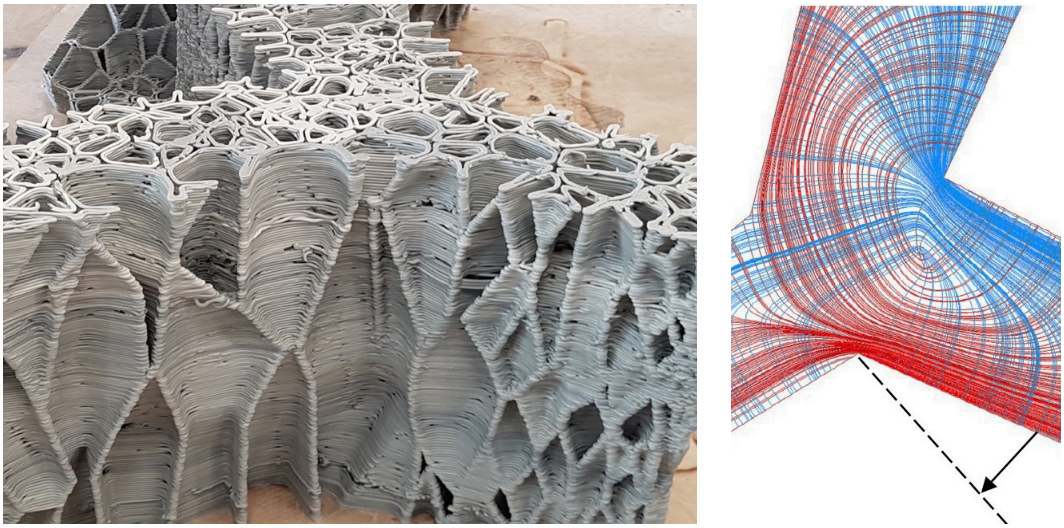


FIGURE 1 Fragment showing the flexible back of the chaise longue and respective structural analysis

Additive manufacturing technologies are enabling fabrication of cellular materials with complex architectures (Schaedler and Carter, 2016). By tailoring the material architecture to specific requirements i.e. by varying cellular architecture, material properties can be customized. In the presented architected material approach, mechanical and physical properties of the structure inform the inner multiscale design. The material has a differentiated cellular pattern allowing for a gradient from high to low density of cells with the purpose of achieving variable stiffness. The control of deformation is based on varying density of cells with variable size, which is based on functional requirements related to how much the overall shape should deform or not. The variable density results from structural requirements, material properties, and extrusion thickness that determine local buckling and elastic deformation.

Material design

Several cellular patterns were developed in order to identify material behavior as well as printability (fig. 1 and 2). The angles of the cells are constrained to 45 degrees in relation to the printing bed in order to reduce material use and printing time. The final cellular architected material approach involved a differentiated pattern consisting of 3D Voronoi cells of various sizes. This implies that the control of stiffness is differentiated thus non-uniform (with some areas being stiffer than others). The advantage of the Voronoi cells is that the cells can gradually change in size from big to small and vice versa. Thus the stiffness can gradually increase or decrease, which contrasts uniform distributions where units could change in size step by step, and therefore the stiffness would increase or decrease incrementally, not gradually. Another advantage is that the Voronoi cell pattern can be printed with continuous tool paths.

FIGURE 2 Chaise longue shape change from lying down (left) to sitting (right) obtained by tuning the stiffness through variable material deposition

The gradual distribution of stiffer and less stiff areas is following structural analysis results (Fig. 1 and 2). The stress lines resulting from structural analysis are transformed into a point cloud that is used to generate the centre points of the Voronoi cells. Since the cell density determines the global and local stiffness, which is also influenced by the stiffness of the material, the points in the data field are increased or decreased to achieve the required local and global density variation. From test prints, it was determined that for the chaise longue 3000 cells would create the required global and local stiffness of the material system. Cell density distribution follows the structural analysis and stiffness is tuned according to simulated stresses. Furthermore, the points are placed strategically so that the edges of the cells are within the printing angle tolerances. While the global density distribution is according to the previous described stiffness requirements, the exact placement is based on the printing angle requirements.

Case studies

The developed architected material has been tested on a chaise longue (Fig. 2) and the developed Design-to-Robotic-Production (D2RP) approach has been scaled up for a Mars habitat (Fig. 3). Both feature adaptive stiffness for facilitating functional requirements.

The chaise longue features a flexible behaviour: The more weight is placed on the back support, the more it deforms, until equilibrium is achieved. When the position changes from upright to reclined position, the stress distribution changes and more weight is positioned on the back support. In order to achieve such range of behaviours, the weight distribution is mapped onto the surface of the chaise longue, which informs local and global cellular patterns. More weight requires higher density of smaller cells to achieve higher degrees of stiffness and vice versa. The objective in this case was to generate a stable chaise longue with a controlled flexible behaviour while using minimal material. Thus larger or smaller cell densities are placed according to the desired stiffness, in order to create softer or stiffer areas where needed.

This approach has been investigated with respect to its feasibility for large scale structures in a project for an underground Martian habitat developed in response to a call for ideas initiated by the European Space Agency (ESA). The proposed idea was to 3D print on top of a Martian concrete layer (Wan et al., 2016) of an underground habitat, a silicon-based sealing layer that allows operation of the life support system. While the layers of soil covering the Martian habitat provide protection against radiation and large temperature fluctuations, the concrete ensures structural stability. The sealing layer printed on top of the concrete facilitates the implementation of pressurized environmental control. Due to the variable stiffness of the architected material, this layer facilitates other functionalities related to the use of the space (Fig. 3) as well. Depending on the specific activities i.e. sleeping, socializing, or working, areas designated for those activities are cushioned or stiffened accordingly.

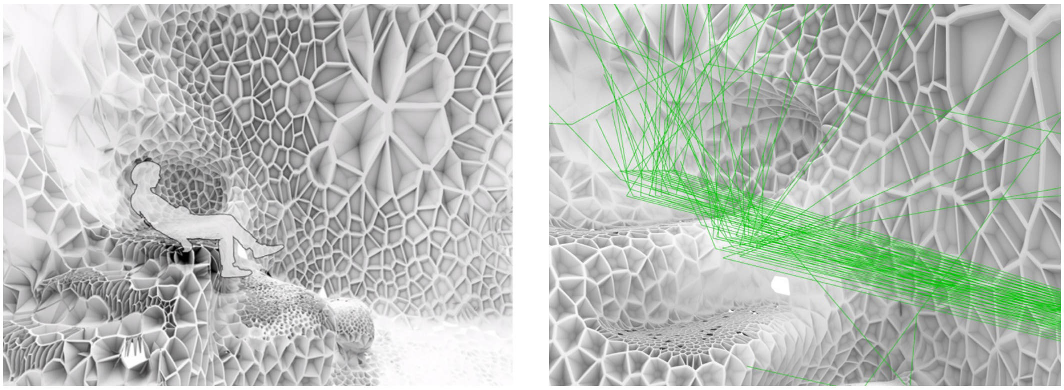


FIGURE 3 Multi-functional adaptive mesh (left) with acoustic properties tested for scattering effects (right)

This is achieved, after performing the structural analysis, to understand the tensile and compressive forces at stake, so that specific stress lines can be used to inform a point cloud, which is the basis of the Voronoi structure. The present study model has been achieved by populating the fragment with 5000 points for experimental purposes. The point cloud is also informed by the functionality of the space. The horizontal surfaces have a higher cell density for creating surfaces to walk, lie, sit or sleep on and some areas are less stiff than others in order to provide cushioning for comfort. In addition to functionalities related to activities, the point cloud is informed by acoustic requirements. According to the acoustic analysis (fig. 3), the surface tectonic based on the Voronoi logic contributes to acoustic comfort. The pattern facilitates sound scattering, preventing sound waves from mirror-bouncing phenomena, which might result in echoing. This capacity of the surface to scatter sound is obtained in addition to the tactile qualities achieved through variable stiffness.

Design-to-Robotic-Production

D2RP links computational design to robotic production. While the D2RP approach in the first case study involved use of the required process and material, the D2RP approach in the second case study involved scaling up design to building scale and emulation of the process (fig. 3, 4 and 5). The involved additive and subtractive processes were reproducing the excavation and the reinforcement processes on Mars but employed materials were different. The milling procedure in EPS was designed in such a way that material removal was gradual along a continuous toolpath (fig. 4 and 5). The continuous path approach was implemented in the additive D2RP process as well only using TPE with glass fiber reinforcement instead of Martian concrete. To avoid having to print a supporting structure, the cells design obeyed the aforementioned 45-degree inclination rule.

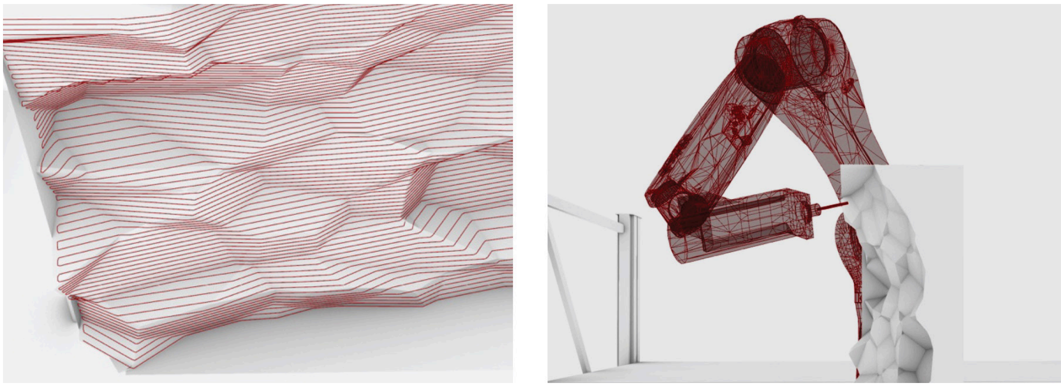


FIGURE 4 Robotic path optimization for subtractive D2RP

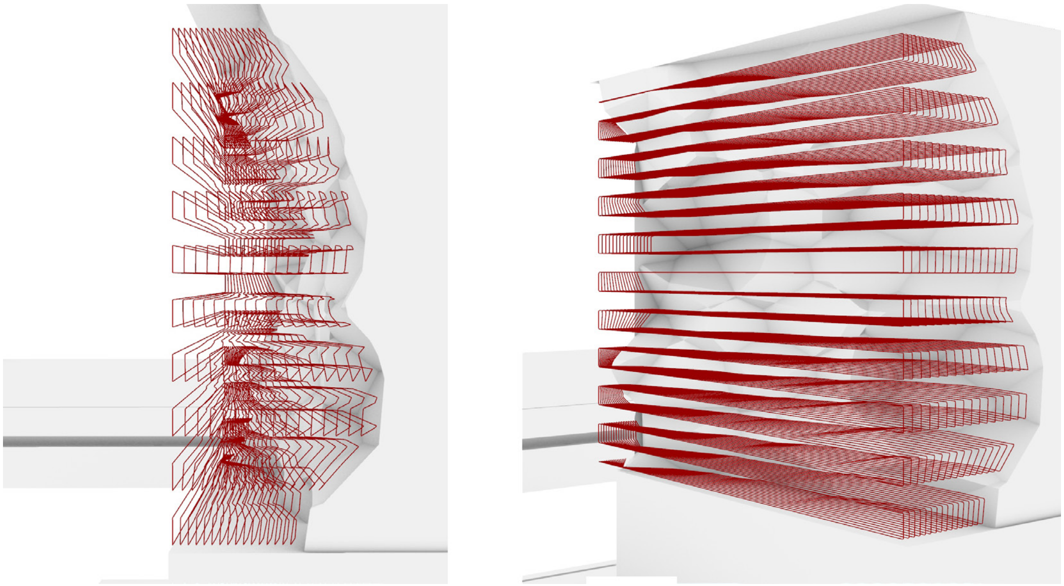


FIGURE 5 Required toolpaths for creating surface tectonics

Conclusion

Numerical and experimental tests have shown that stiffness variation is feasible and the use of architected materials with variable stiffness facilitates structural adaptation. In the presented case, the developed architected material ensures variable stiffness through the gradient pattern differentiation. The material is customisable and the 3D printing process allows for mass customisation of products.

Future work will further investigate feasibility of this approach for large scale structures. In particular the integration of various functionalities required for indoor environments involving not only furnishing as presented in this paper but also sensor-actuator networks for environmental control will be of particular relevance.

Acknowledgements

This project has been implemented with funding from 4TU Bouw and with the printing system of 3D Robot Printing. The application at building scale has been developed with researchers and MSc students. It profited from the feedback of ESA experts.

References

Schaedler, T. A., & Carter, W. B. (2016). Architected cellular materials. Annual Review of Materials Research, 46, 187-210.

Wan, L., Wendner, R., & Cusatis, G. (2016). A novel material for in situ construction on Mars: experiments and numerical simulations. Construction and Building Materials, 120, 222-231.

EXCASAFEZONE

Synthesizing Expert Based ‘On-The-Fly’ Safety Risk Heat Maps

Léon olde Scholtenhuis [1], **Farid Vahdatikhaki** [1], **Sisi Zlatanova** [2], **Jakob Beetz** [3], **Pieter Pauwels** [3]

[1] *University of Twente*
[2] *Delft University of Technology*
[3] *Eindhoven University of Technology*

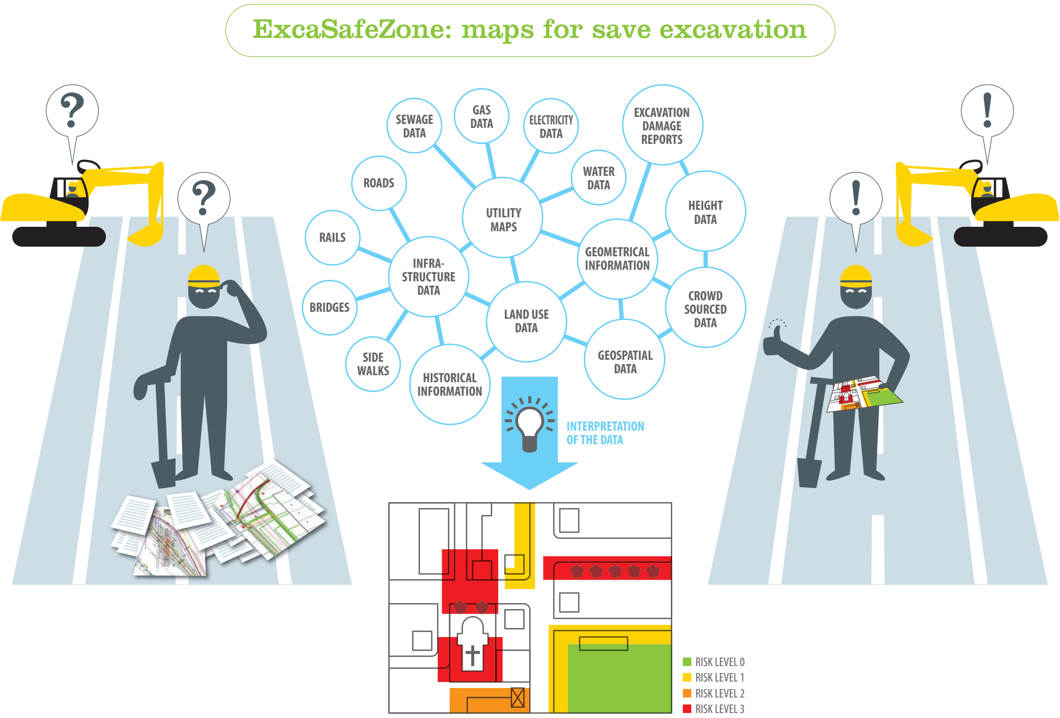
Abstract

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.

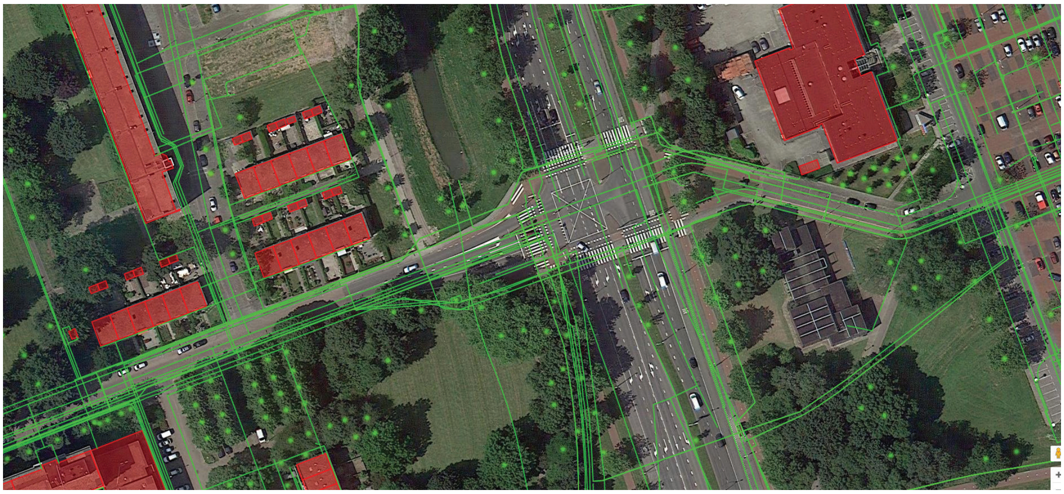
Keywords

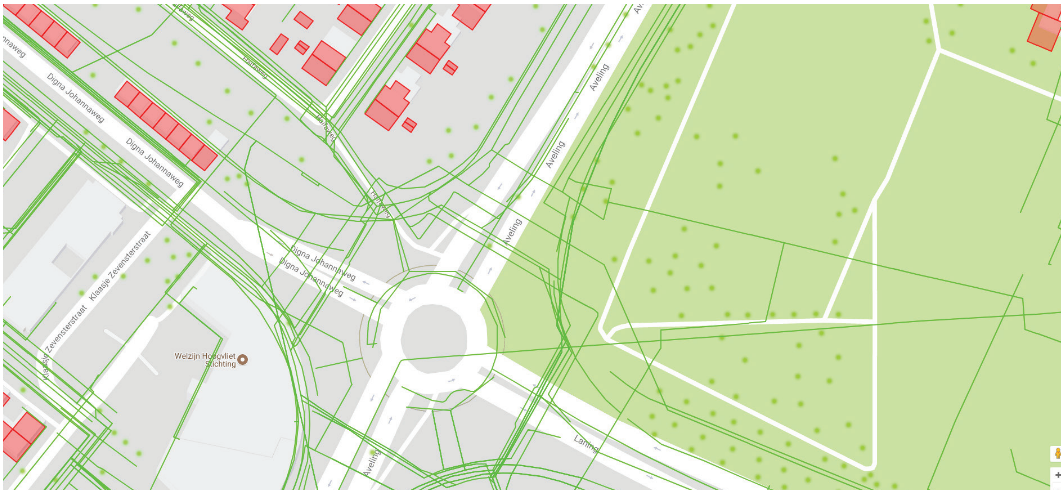
excavation, data, risk, information system, construction, objects

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 (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.

GEOCON BRIDGE

Geopolymer Concrete Mixture for Structural Applications

Guang Ye [1], **Mladena Luković** [1], **Bahman Ghiassi** [1], **Zainab Aldin** [1], **Silke Prinsse** [1], **Jonh Liu** [1], **Marija Nedeljković** [1], **Dick Hordijk** [1], **Paul Lagendijk** [1], **Albert Bosman** [1], **Ton Blom** [1], **Maiko van Leeuwen** [1], **Zhekang Huang** [1], **Ulric Celada** [1], **Chengcheng Du** [1], **John van den Berg** [1], **Arjan Thijssen** [1], **Simon Wijte** [2]

[1] *Faculty of Architecture and the Built Environment*
Delft University of Technology
[2] *Faculty of the Built Environment*
Eindhoven University of Technology

Abstract

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.

Keywords

concrete, geopolymer, reinforced, strength, bridge, compressive

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 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.

table 1

FIGURE 1 Slump test of optimized concrete mixture.

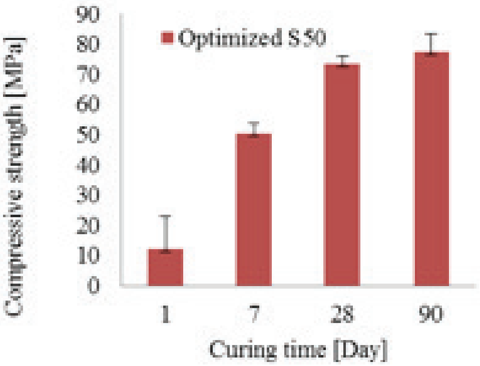


FIGURE 2 Compressive strength test results for reference and optimized mixture.

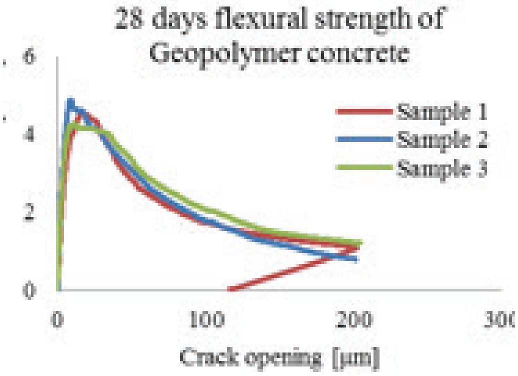


FIGURE 3 Flexural strength at 28 days.

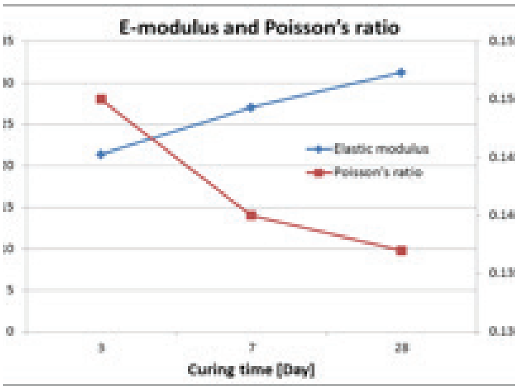
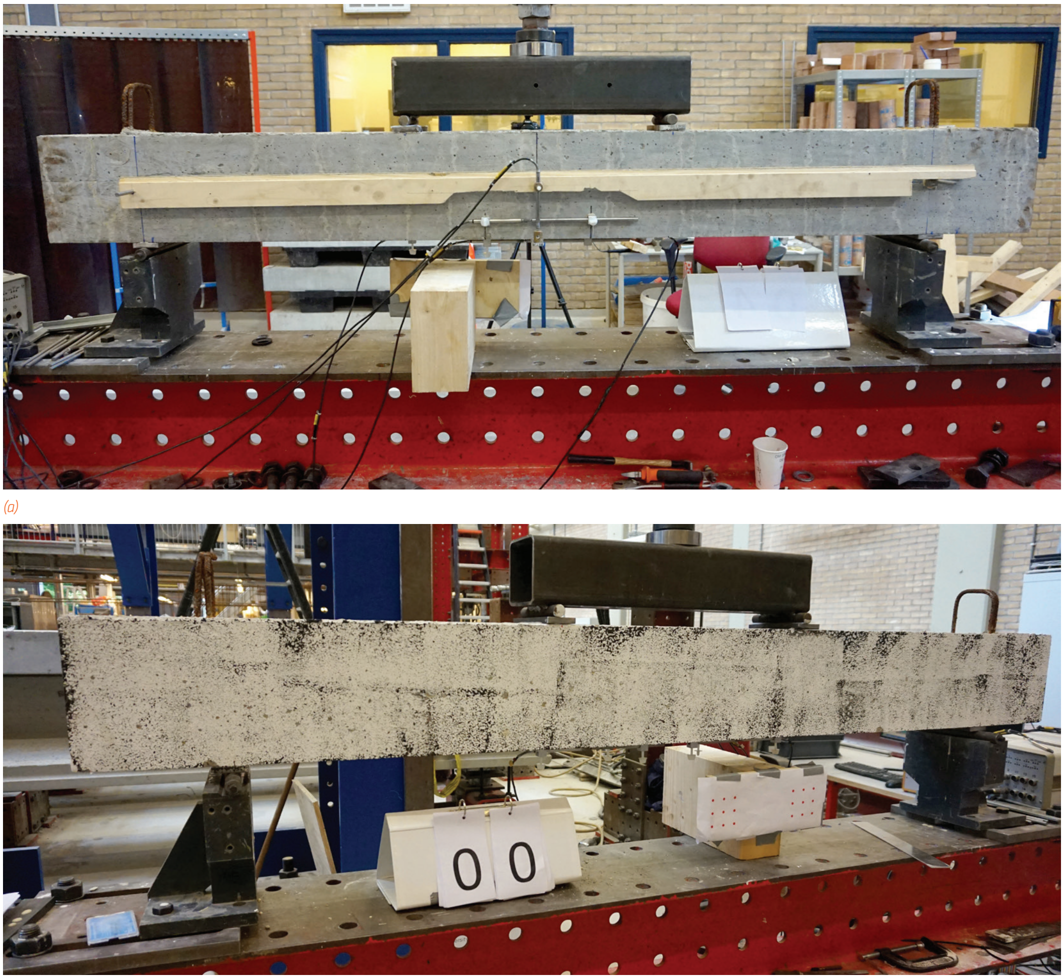


FIGURE 4 E-modulus and Poisson's ratio.

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.



(a)

(b)

FIGURE 5 Test set-up: painted side of beam for image analysis (a) and LVDTs to measure deformation (b).

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). 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.

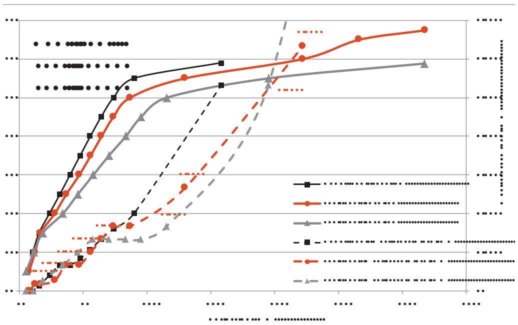


FIGURE 6 Development of cracks during four-point bending tests on S50 beams at 33 and 69 days and comparison with OPC concrete control beam, results by Zhekang Huang. S50 specimens have been cured (20°C and 95% RH) for 28 days. After this, the samples were exposed to laboratory conditions (20°C and 55%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

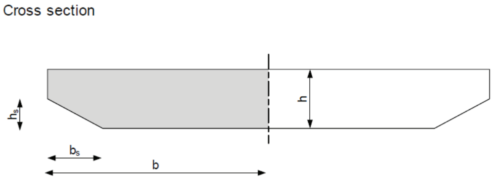
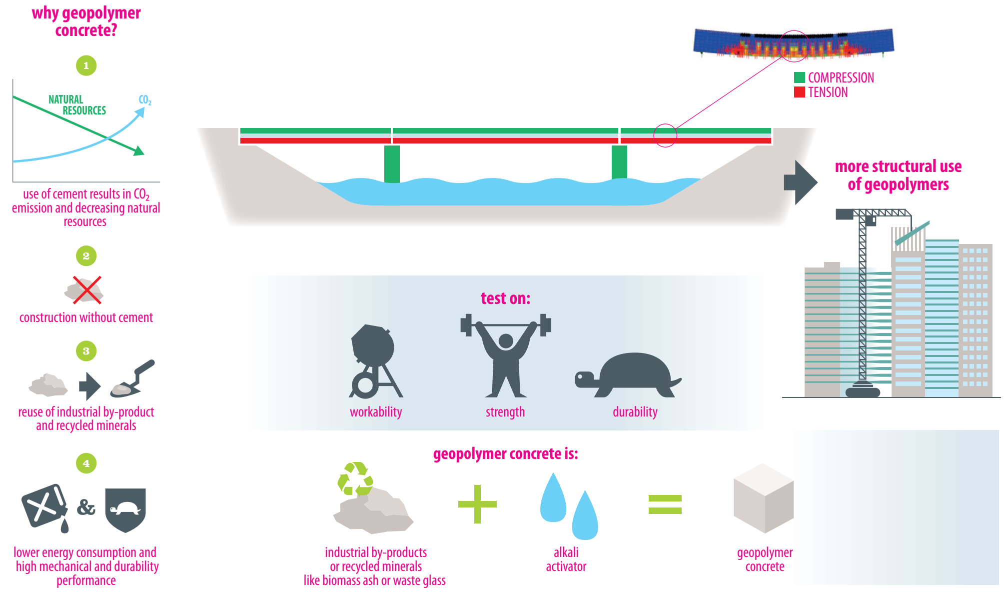


FIGURE 7 Geopolymer concrete bridge

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.

FIGURE 8 Reinforced geopolymer concrete bench made of the optimized geopolymer concrete mixture. The bench has been located in the street G.J. de Jonghweg, Rotterdam.



CREATIVEPROJECTS 2017

Main output of the project

- 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 (Fig.8) and news in https://www.rotterdam.nl/nieuws/groene-betonbank/
- The work performed in the group of Concrete Structures was done within the MSc thesis project of Silke Prinsse.

Happy Senior Living

65+ Best Living Concepts

Ioulia Ossokina [1], **Theo Arentze** [1], **Dick van Gameren** [2], **Dirk van den Heuvel** [2]

[1] *Faculty of the Built Environment*
Eindhoven University of Technology
[2] *Faculty of Architecture and the Built Environment*
Delft University of Technology

Abstract

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.

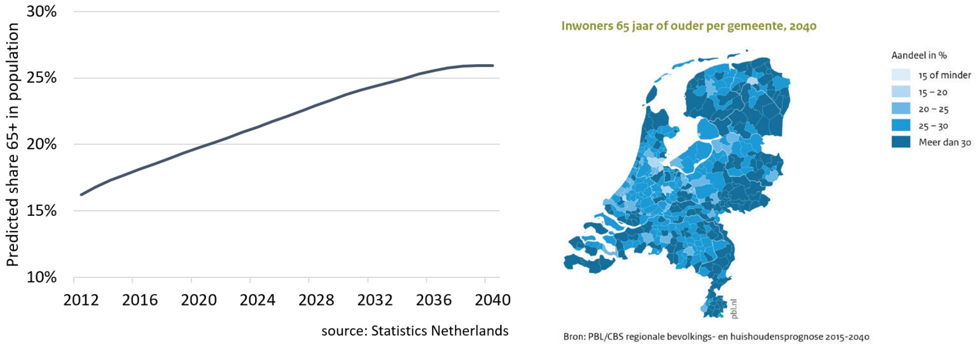
Keywords

toolbox, dwelling, building, elderly, attributes, living

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 m^2 and 110 m^2, 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 m^2;
- balcony 12 m^2;
- 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.



source: Statistics Netherlands

Bron: PBL/CBS regionale bevolkings- en huishoudensprognose 2015-2040

(a) *(b)*

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

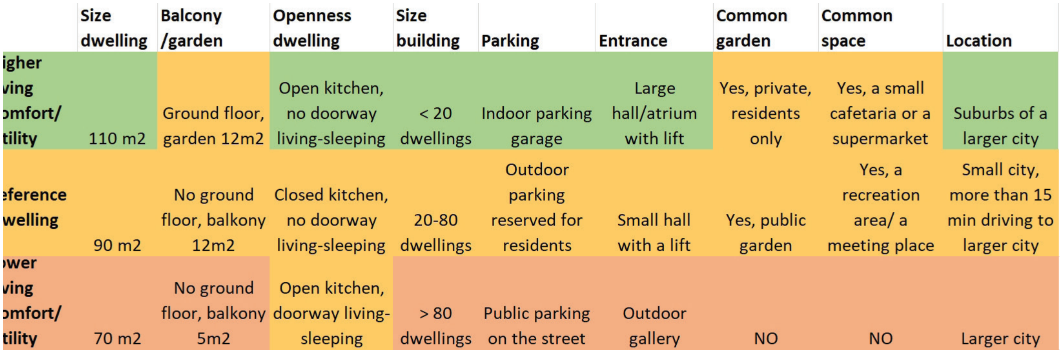
Consumer toolbox and the best living concepts

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 m^2 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.



	Size dwelling	**Balcony /garden**	**Openness dwelling**	**Size building**	**Parking**	**Entrance**	**Common garden**	**Common space**	**Location**
igher ving omfort/ tility	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
eference welling	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
ower ving omfort/ tility	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

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.

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.

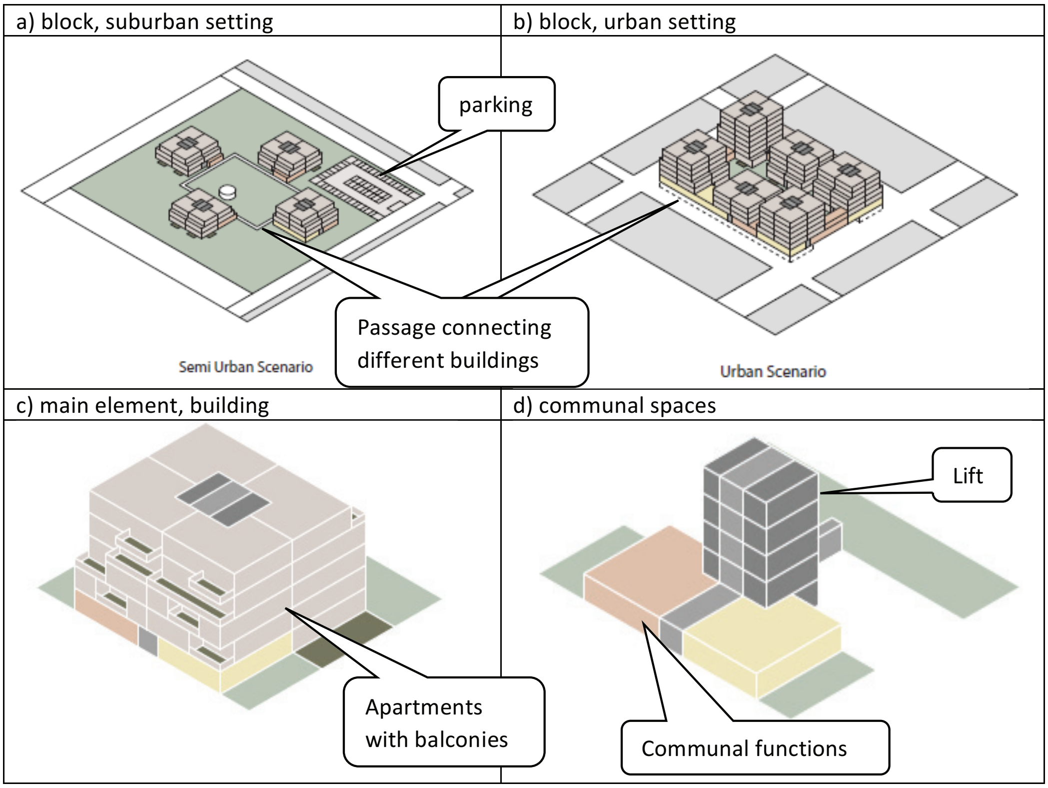
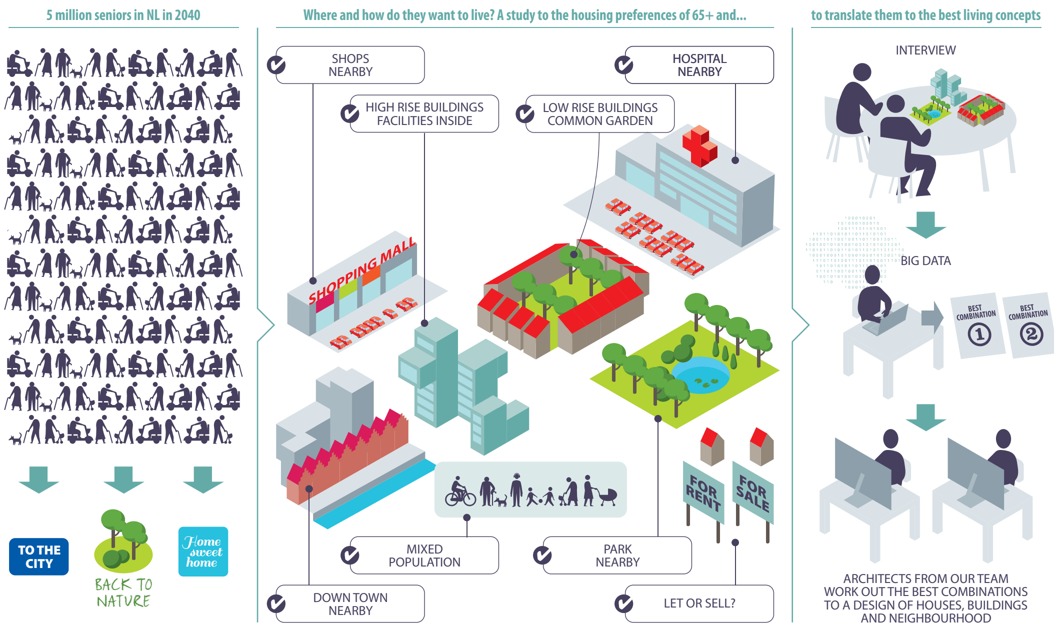


FIGURE 3 Architectural toolbox, extract.



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.

Re-Printing Architectural Heritage

Exploring Current 3D Printing and Scanning Technologies

Juliette Bekkering [1], **Barbara Kuit** [1], **Carola Hein** [2], **Michaela Turrin** [2], **Joris Dik** [2], **John Hanna** [2], **Miktha Alkadri** [2], **Serdar Asut** [2], **Ulrich Knaack** [2], **Peter Koorstra** [2], **Albert Reinstra** [3], **Angela Dellebeke** [4], **Dave Vanhove** [5], **Dick Vlasblom** [6], **Jur Bekooy** [7], **Ron Teeuw** [8], **Valentin Vanhecke** [9], **Wim Oostveen** [10]

[1] *Eindhoven University of Technology*
[2] *Delft University of Technology*
[3] *Cultural Heritage Agency of the Netherlands*
[4] *National Archives*
[5] *3D idea printing*
[6] *QUBICX*
[7] *Foundation for Old Groningen Churches*
[8] *BLOMSMA PRINT&SIGN*
[9] *4Visualization*
[10] *3M Netherlands*

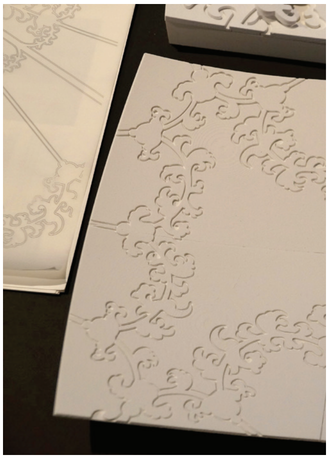
Abstract

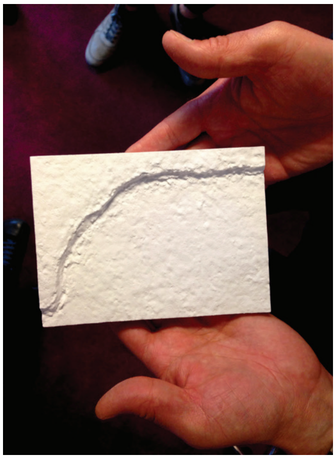
Additive Manufacturing (commonly known as 3D printing) technology has become a global phenomenon. In the domain of heritage, 3D printing is seen as a time and cost efficient method for restoring vulnerable architectural structures. The technology can also provide an opportunity to reproduce missing or 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.

Keywords

3D printing, 3D scanning, heritage, architecture

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.

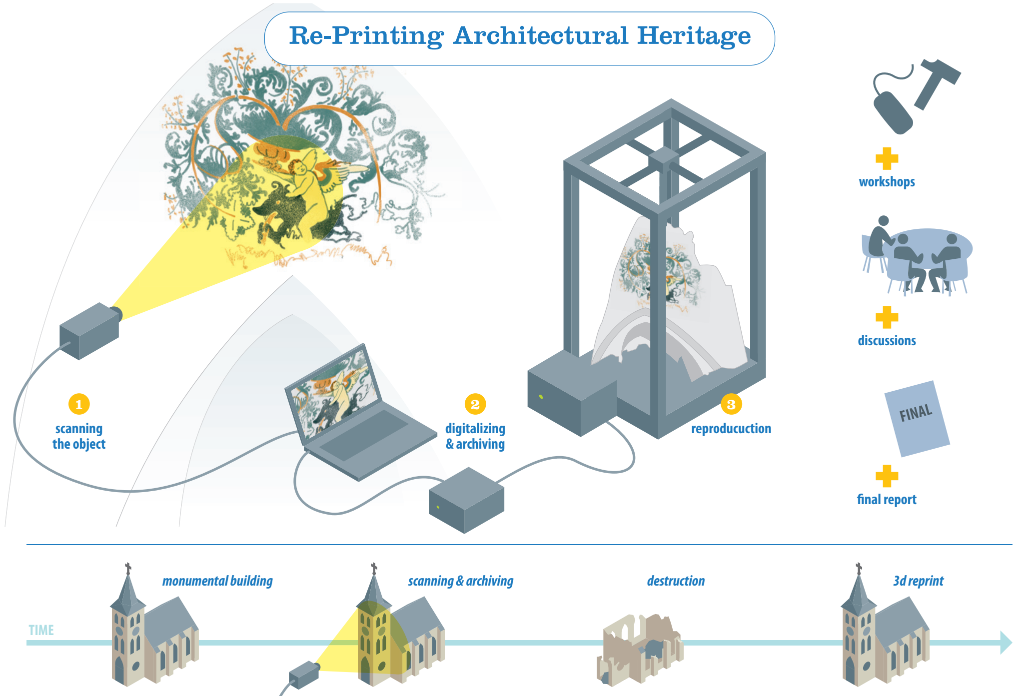
Having separated the structural printing and that of the film, we opted to first experiment with materials for 3D structural (non-colored) 3D printing. The CAMlab of TU Delft produced a first gypsum test print without color, providing a good first impression of the surface structure. We found that the 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.



CREATIVEPROJECTS 2017

Re^3 Glass

a Reduce/Reuse/Recycle Strategy

Telesilla Bristogianni [1], **Faidra Oikonomopoulou** [1], **Lida Barou** [1], **Fred Veer** [1], **Rob Nijsse** [1], **Erwin Jacobs** [1], **Giulia Frigo** [1], **Elma Durmisevic** [2], **Pieter Beurskens** [2], **Jiyong Lee** [3], **Katherine Rutecki** [3]

[1] *Faculty of Architecture and the Built Environment*
Delft University of Technology
[2] *University of Twente*
[3] *School of Art and Design*
Southern Illinois University

Abstract

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.

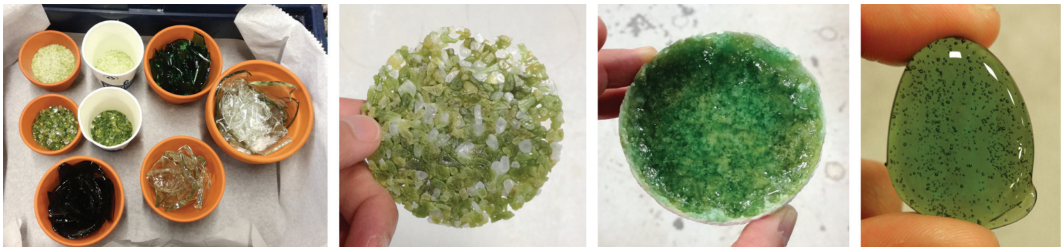
Keywords

glass, components, cast, interlocking, structures, recycling, waste

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:

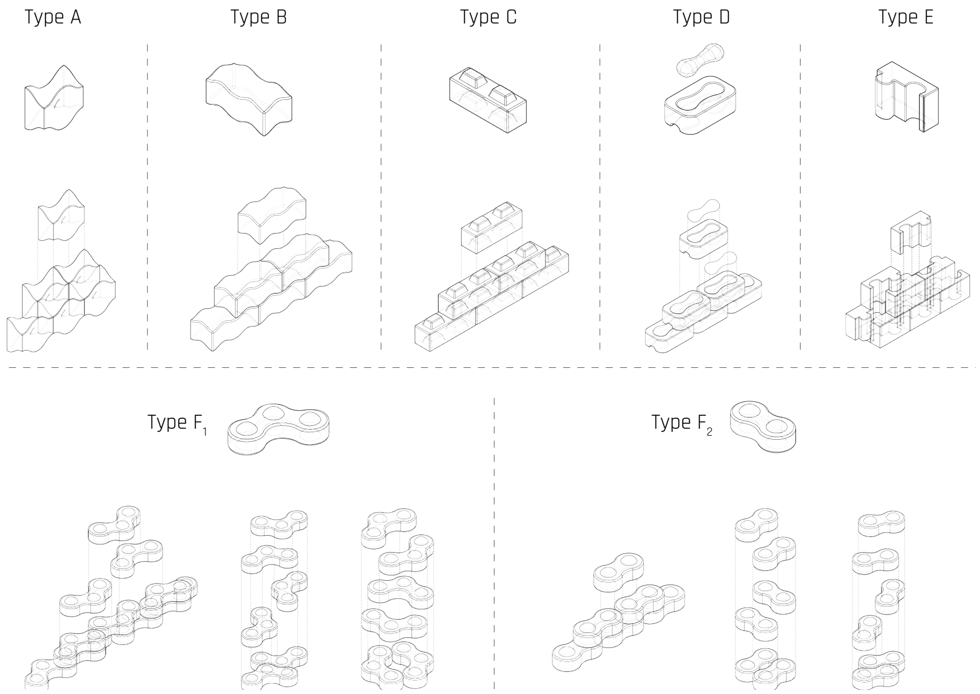
Step 1. REcycle by employing waste glass

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

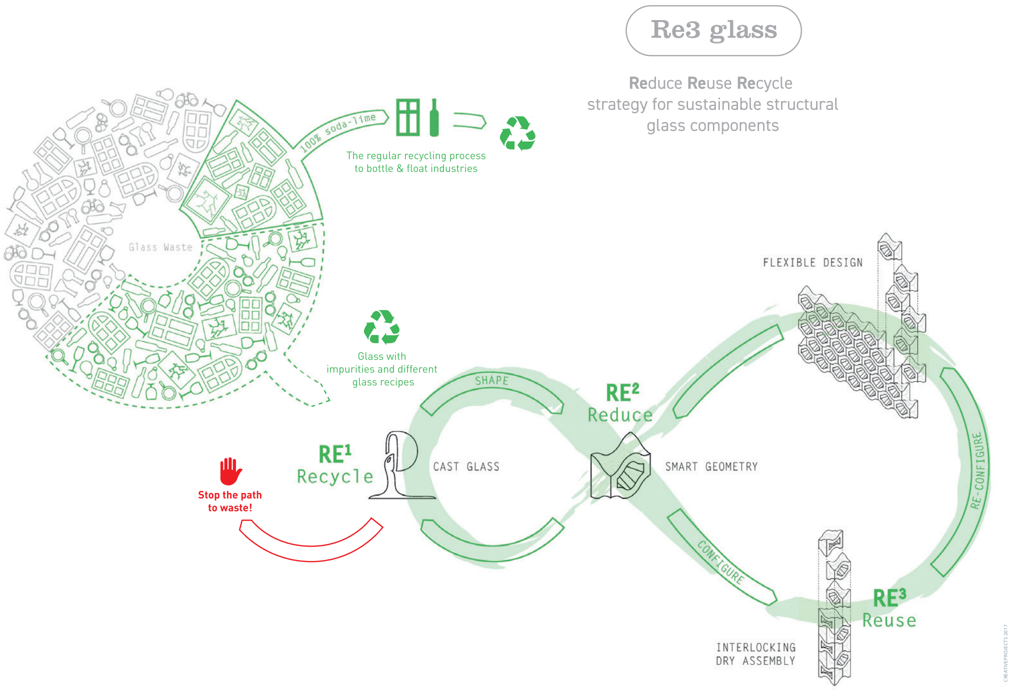
Currently, the few realized structures using cast glass components employ either a steel substructure or an adhesive of high bonding strength, typically less than 2 mm thick, to ensure the rigidity and lateral stability of the construction. Whereas the first solution compromises the overall level of 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 “Re^3 Glass” project is the new generation of REcyclable, REducible and REusable cast glass components, which suggests an inno-vative and sustainable way of building with glass.



Terra-Ink

Additive Earth Manufacturing for Emergency Architecture

Tommaso Venturi [1], **Michela Turrin** [1], **Foteini Setaki** [1], **Fred Veer** [1], **Arno Pronk** [2], **Patrick Teuffel** [2], **Yaron Moonen** [2], **Stefan Slangen** [2], **Rens Vorstermans** [2]

[1] *Faculty of Architecture and the Built Environment*
Delft University of Technology
[2] *Faculty of the Built Environment*
Eindhoven University of Technology

Abstract

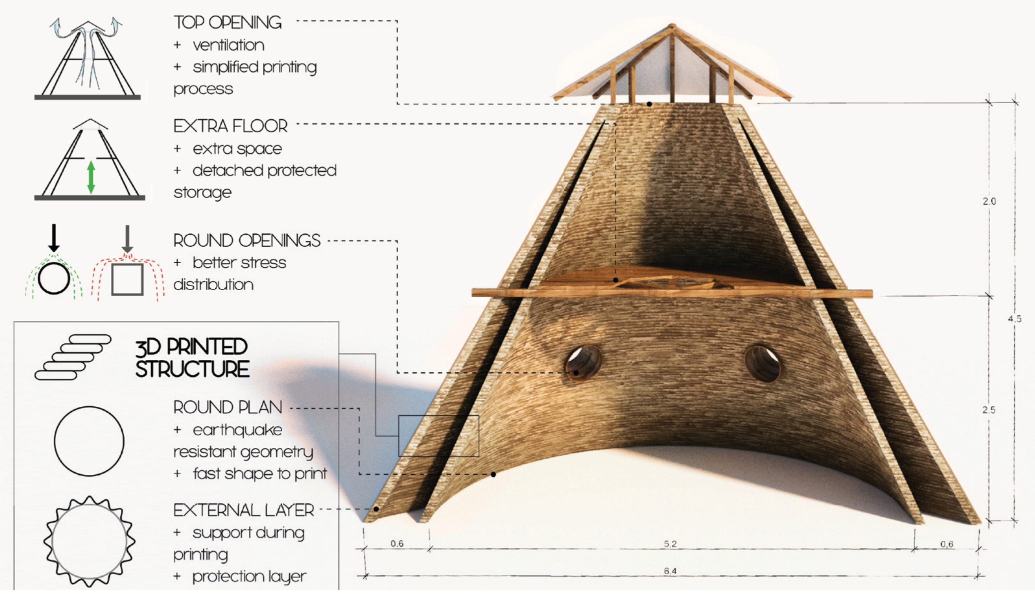
In recent years, natural disaster and military conflicts forced vast numbers of people to flee their home countries, contributing to the migration crisis we are facing today. According to the UNHCR, the number of forcibly displaced people worldwide reached the highest level since World War II. Post-disaster 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.

Keywords

soil, material, process, mixture, emergency, temporary, structure, extrusion

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.

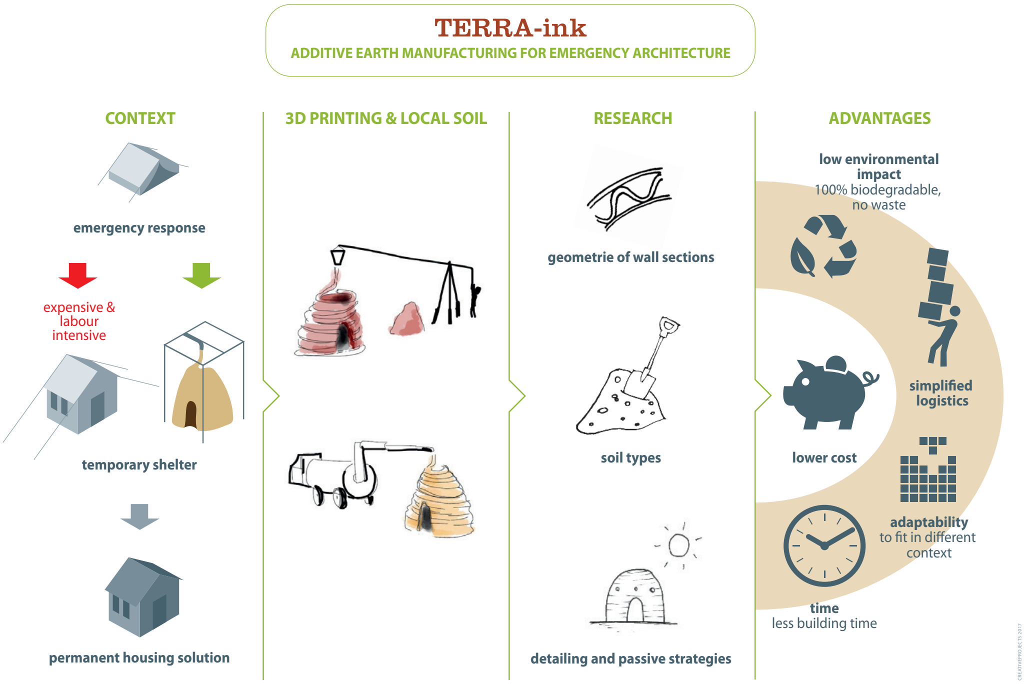


Aiming to increase the flexibility and adaptability of the process, the project examined the potential of a construction system based on the deposition of soil material, without relying on a specific technology or material recipe, but rather adjusting to the available resources. During the project, the 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.

Air Curtain Optimization

Claudio Alanis Ruiz [1], **Twan van Hooff** [1], **Bert Blocken** [1]

[1] *Faculty of the Built Environment*
Eindhoven University of Technology

Abstract

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.'.

Keywords

curtains, air, efficiency, jet, environmental, separation, parameters, temperature

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.

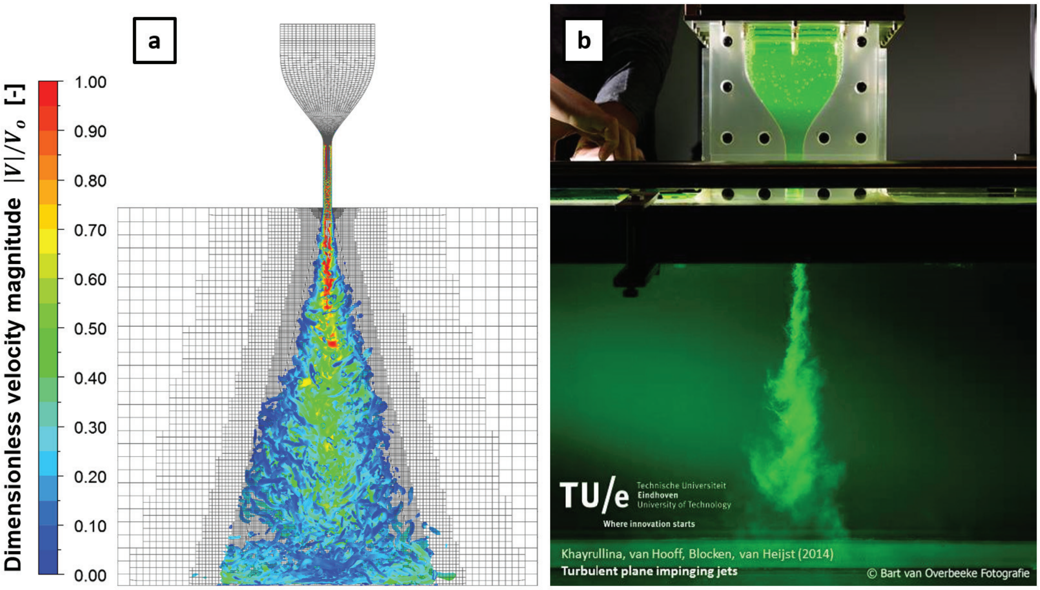


FIGURE 1 (a) Velocity magnitude contours of an impinging jet obtained from CFD simulation (large eddy simulation). (b) Visualization of impinging jet flow in a water tank experiment (Khayrullina et al., 2017).

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. 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.

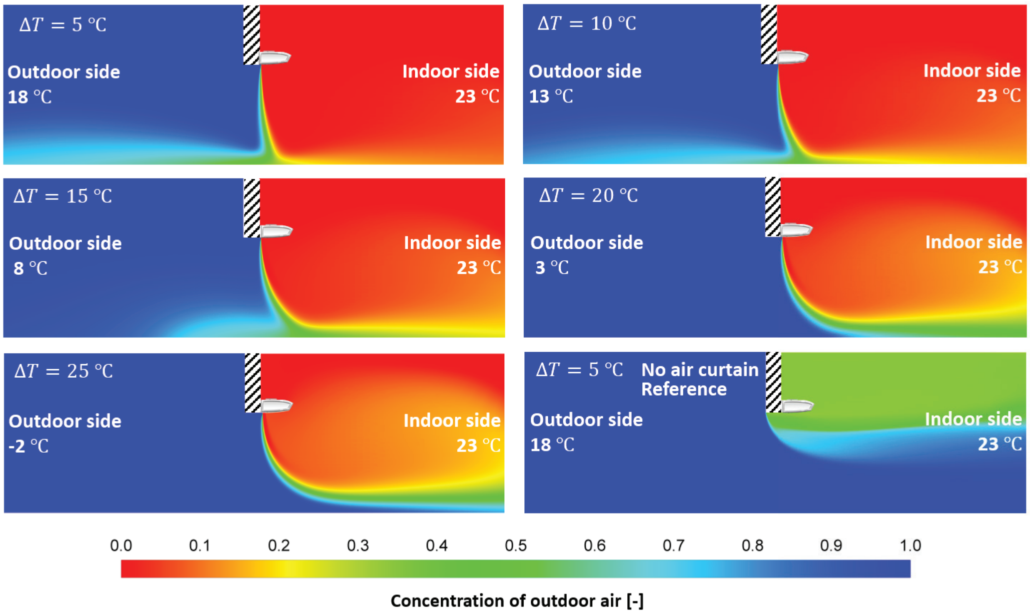
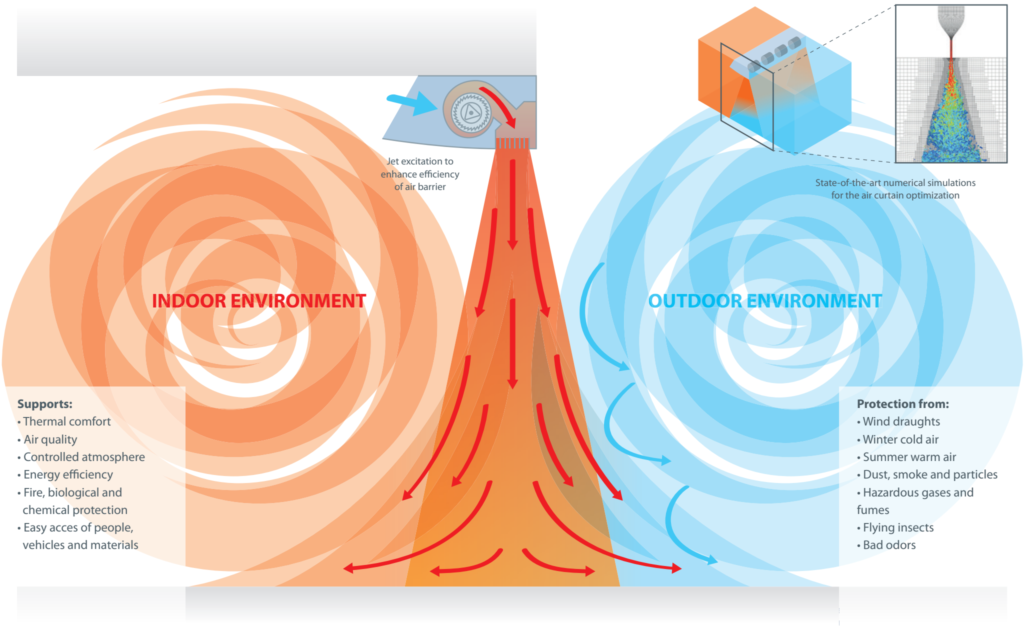


FIGURE 2 Effect of the variation in cross-jet temperature gradients (5°C ≤ ΔT ≤ 25°C) on air curtain performance. The colors indicate the concentration of outdoor air (dark blue = 100% concentration of outdoor air, dark red = 0% concentration of outdoor air).

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.



Supports:
- Thermal comfort
- Air quality
- Controlled atmosphere
- Energy efficiency
- Fire, biological and chemical protection
- Easy acces of people, vehicles and materials

Protection from:
- Wind draughts
- Winter cold air
- Summer warm air
- Dust, smoke and particles
- Hazardous gases and fumes
- Flying insects
- Bad odors

CREATIVE PROJECTS AMSTERDAM

Sustainable Performance Optimization for Digital Housing

Randy van Eck [1], **Bauke de Vries** [1], **A. Wijnen** [2], **K. Nix** [2], **J. van den Heuvel** [2]

[1] *Faculty of the Built Environment*
Eindhoven University of Technology
[2] *De Twee Snoeken*

Abstract

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.

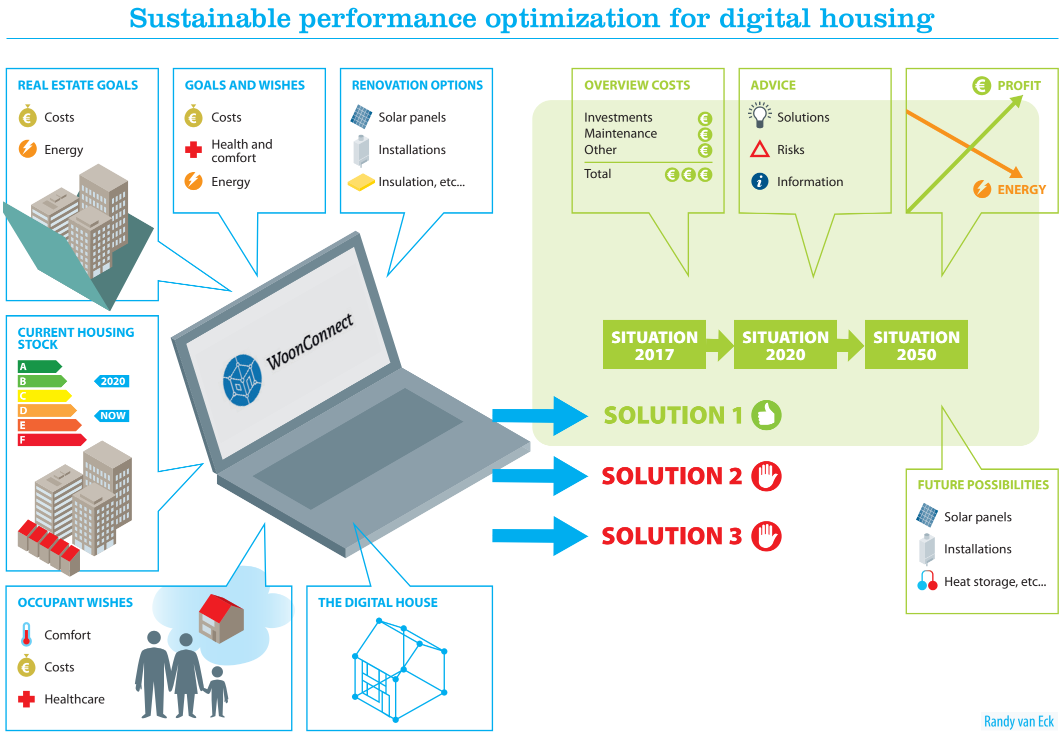
Keywords

building, different, WoonConnect, users, tool, interface, digital

Expanding WoonConnect

To further develop this tool the aim is to integrate the following aspects within WoonConnect:

1. 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.
2. 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.
3. 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.


Sustainable performance optimization for digital housing

Randy van Eck

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.

spool

www.spool.tudelft.nl

9 789463 662468