

Fibrous smart material

adaptive, low-energy, real-time
responsive interior environments

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Abstract

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

Keywords

heterogeneous fibres; smart furniture systems; multi-layered fibre compositions; real-time structural adaptability

These smart furniture systems will embody properties of real-time adaptive temperature control, real-time structural adaptability and real-time physiological support of the human body.

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

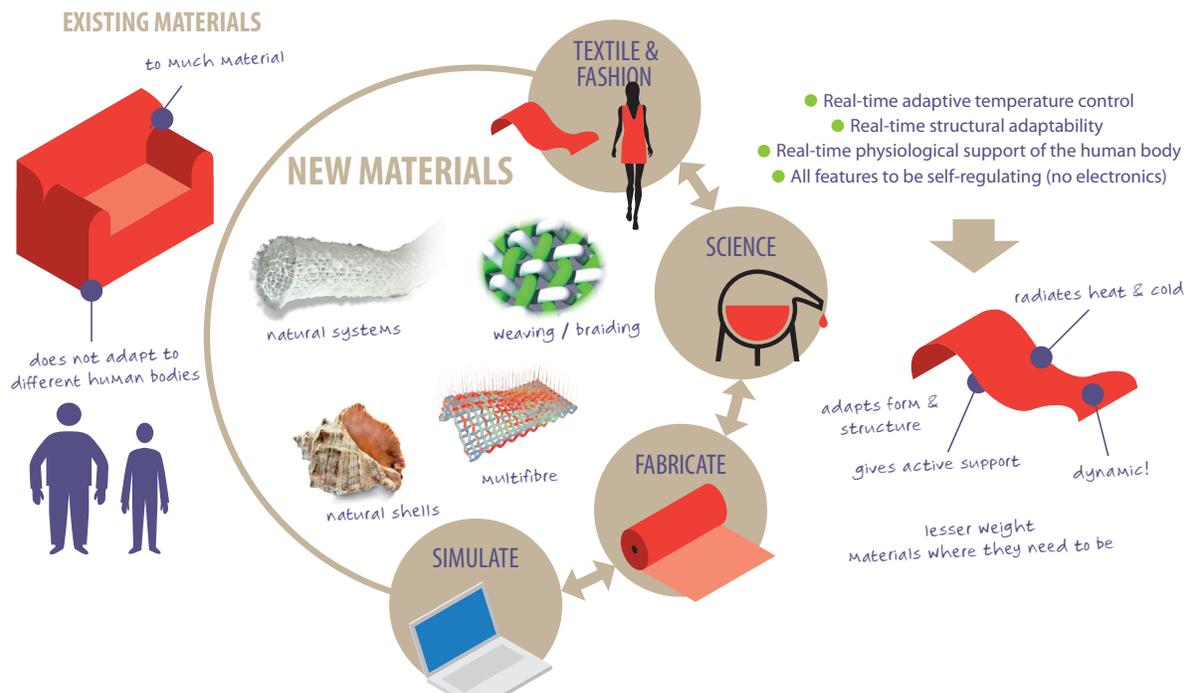


FIGURE 1 Graphical abstract

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

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

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

Support

- Eindhoven University of Technology
- University of Twente
- EURECAT
- Atelier Robotic



FIGURE 2

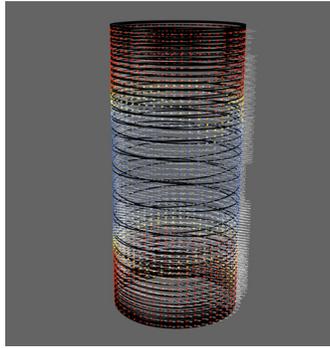


FIGURE 3



FIGURE 4



FIGURE 5

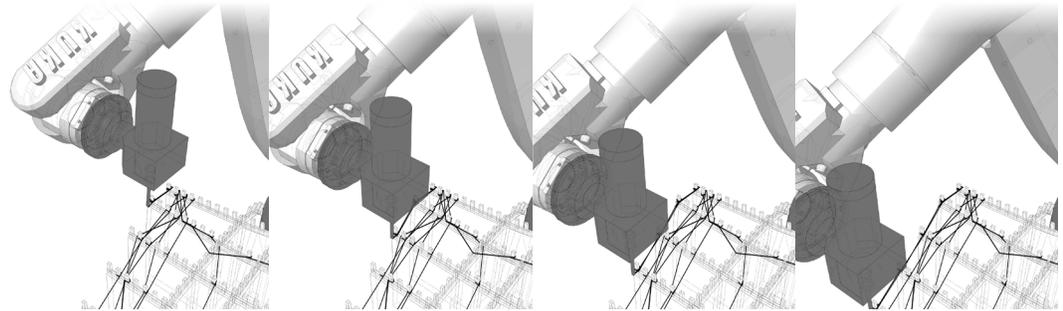


FIGURE 6

Optimizing 3D concrete printing

exploring potentials and limitations
of materials and production

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Abstract

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

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

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

Keywords

optimised 3D concrete printing; Computer Aided Manufacturing; digital manufacturing;
Additive Manufacturing

Context

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

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

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

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

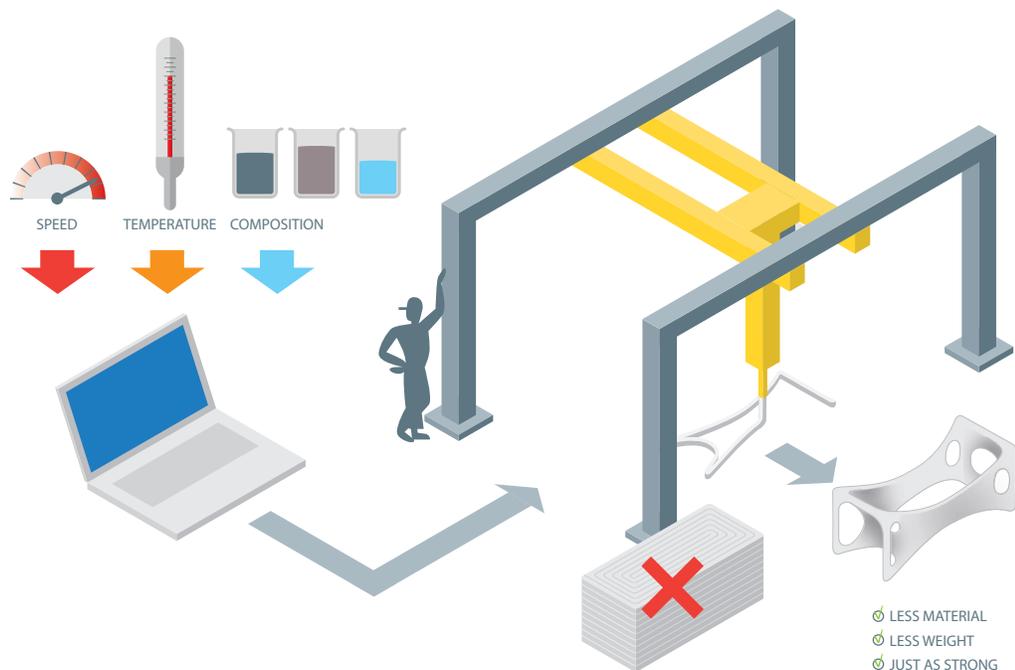


FIGURE 1 Graphical abstract

The first steps towards an environment in which geometries can be optimised whilst taking the properties and limitations of a 3D concrete printer and the resulting material properties into account.

Project

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



FIGURE 2

Printer properties

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

- Vertical cantilevering angle between layers;
Without the use of a support material the layers can only cantilever a few degrees, both in the printing direction, as well as perpendicular to that direction.
- Printing direction;
In this project the printing direction is kept constant. Layers are printed next to each other and on top of each other.
- Nozzle width and layer height;
The nozzle width and the layer height can be chosen at the start of the optimisation.

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

Material properties

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

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

Optimisation

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

Results

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

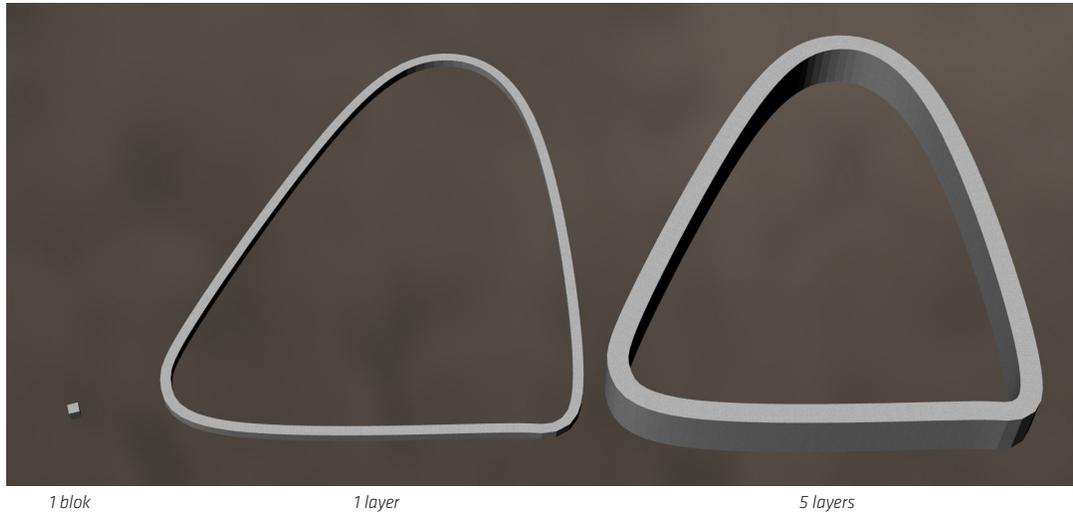


FIGURE 3

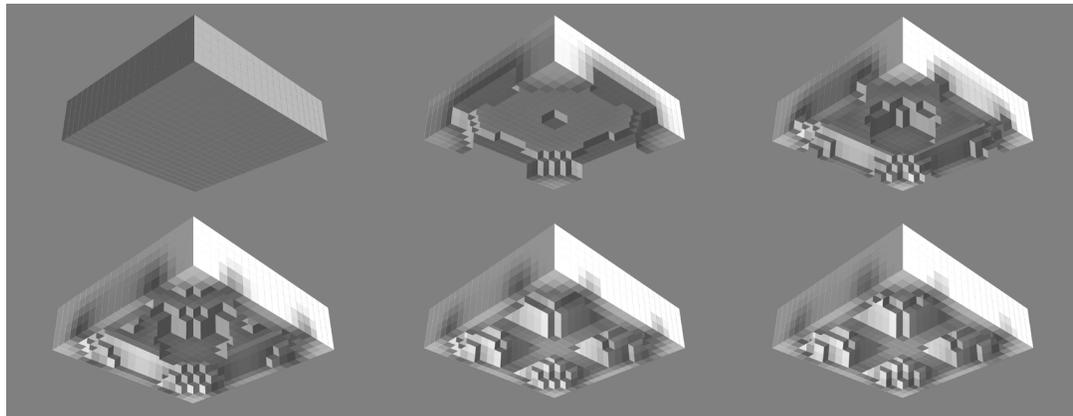


FIGURE 4