JANUARY 19TH 2017 – MUNICH

# POWERSKIN CONFERENCE

**PROCEEDINGS**

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The Building Skin has evolved enormously over the past decades. Energy performance and environmental quality of buildings are significantly determined by the building envelope. The façade has experienced a change in its role as an adaptive climate control system that leverages the synergies between form, material, mechanical and energy systems in an integrated design.

The PowerSkin Conference aims to address the role of building skins to accomplish a carbon neutral building stock. Topics such as building operation, embodied energy, energy generation and storage in context of façades, structure and environment are considered.
Three main themes will be showcased in presentations of recent scientific research and developments as well as projects related to building skins from the perspectives of material, technology and design:

**Environment** – Façades or elements of façades which aim for the provision of highly comfortable surroundings where environmental control strategies as well as energy generation and/or storage are integral part of an active skin.
**Façade Design** – The building envelope as an interface for the interaction between indoor and outdoor environment. This topic is focused on function and energy performance, technical development and material properties.
**Façade Engineering** – New concepts, accomplished projects, and visions for the interaction between building structure, envelope and energy technologies.

**TU München**, Prof. Dipl.-Ing. Thomas Auer, **TU Darmstadt**, Prof. Dr. Ing. Jens Schneider and **TU Delft**, Prof. Dr.-Ing. Ulrich Knaack are organizing the PowerSkin Conference in collaboration with BAU 2017. It is the first event of a biennial series. On January 19th, 2017 architects, engineers and scientists present their latest developments and research projects for public discussion.


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# Preface

The "third skin" of human beings – the building envelope – has a long history of development with a major impact on architecture. As an interface between inside and outside, facades not only determine aspects such as performance and energy efficiency, they also determine the aesthetics of buildings and cities; to the extend that they can create cultural identity. The invention of the curtain wall made facades independent from the building structure, but it remained an important – yet passive – element.

In the past 2 decades, the building envelope has experienced a change in its role as an adaptive climate control system that leverages the synergies between form, light, material, energy and mechanical systems in an integrated manner. Contemporary façade design aims for an optimized environmental quality while minimizing the use of resources. Indoor environmental quality and operational energy performance were a main focus in the 1990s, whereas in the next decade, design and research also put more and more consideration into outdoor environmental quality. Current research is focusing on materiality in the context of building life cycle, design integration and maintenance. Sustainable, smart materials – providing an auto-reactive, passive environmental control mechanism – as well as active systems for environmental control, along with energy generation and storage became areas for both R&D and construction practice.

Over the past decades, glass developed into the dominating cladding material due to its improved thermal performance and adaptability with regard to transparency, solar and daylight control. This allows a flexible interaction between the indoor and outdoor environment and offers the potential of a dynamic control strategy. Recent developments provide an integration of mechanical climate control systems – such as decentralized mechanical ventilation – and components for energy generation and storage.

On the one hand, this could lead to a building design that is fully independent of local climate conditions, building culture, and other contextual aspects, while still providing an optimized environmental quality. On the other hand, it also enables architects and engineers to design buildings that interact with and adapt to climate conditions and user demands as well as respect local conditions and local context. Such a design approach provides the opportunity to bring the local identity back into the architectural language.

The PowerSkin Conference and the proceedings address three main topics: Façade, Structure and Environment. The presentations and papers showcase recent scientific research and developments, along with projects related to building skin from the perspectives of material, technological and design.

We would like to express our thanks and appreciation to our peers and colleagues, willing to participate in the intensive process of reviewing abstracts and papers – supporting the experienced conference participants to further develop and improve. Special thanks to Prof. Dr. Anne Beim / KADK Copenhagen; Paul Carew / PJC Consulting Cape Town; Prof. Dr.-Ing. Tillmann Klein / TU Delft and TU München; Prof. Dr. Stephen Selkowitz, Lawrence Berkley National Lab (LBNL); Prof. Dr.-Ing. Frank Wellershoff / HafenCity University Hamburg. Also we would like to thank Thaleia Konstantinou / TU Delft; Phoebus Ilias Panigyrakis / TU Delft; Véro Crickx / Rotterdam and Frank van der Hoven / TU Delft for their support with the journal and the conference proceeding.

And finally: our biggest thank you goes to Uta Stettner / TU München and Miriam Schuster / TU Darmstadt – they were the engine pushing the development process and the conference itself. Great work!

*Thomas Auer*
*Ulrich Knaack*
*Jens Schneider*



### Prof. Dipl.-Ing. Thomas Auer

*Trained as a Process Engineer at the Technical University in Stuttgart, Thomas is a partner and managing director of Transsolar GmbH, a German engineering firm specialized in energy efficient building design and environmental quality with offices in Stuttgart, Munich, Paris and New York. In January of 2014 Thomas became Professor for building technology and climate responsive design at the TU Munich.*
*Thomas collaborated with world known architecture firms on numerous international design projects and competitions. A specialist in the fields of integrated building systems and energy efficiency in buildings as well as sustainable urban design, Thomas has developed concepts for projects around the world noted for their innovative design and energy performance – an integral part of signature architecture. The office tower for Manitoba Hydro in downtown Winnipeg, Canada – is considered one of the most energy efficient high-rise buildings in North America. Lower Don lands, Toronto – is going to be among the first carbon neutral districts in North America.*
*Outside of Transsolar, Thomas taught at Yale University and was a visiting professor at the ESA in Paris and other Universities. He speaks frequently at conferences and symposia. In 2010 Thomas received the Treehugger "best of green" award as "best engineer".*

### Prof. Dr.-Ing. Ulrich Knaack

*Prof. Dr.-Ing. Ulrich Knaack (1964) was trained as an architect at the RWTH Aachen / Germany. After earning his degree he worked at the university as researcher in the field of structural use of glass and completed his studies with a PhD.*
*In his professional career Knaack worked as architect and general planner in Düsseldorf / Germany, succeeding in national and international competitions. His projects include high-rise and office buildings, commercial buildings and stadiums.*
*In his academic career Knaack was professor for Design and Construction at the Hochschule OWL / Germany. He also was and still is appointed professor for Design of Construction at the Delft University of Technology / Faculty of Architecture, Netherlands where he developed the Façade Research Group. In parallel he is professor for Façade Technology at the TU Darmstadt / Faculty of Civil engineering/ Germany where he participates in the Institute of Structural Mechanics and Design.*
*He organizes interdisciplinary design workshops and symposiums in the field of façades and is author of several well-known reference books, articles and lectures.*

### Prof. Dr.-Ing. Jens Schneider

*Prof. Dr.-Ing. Jens Schneider (1969) is a full professor for structural engineering at the Institute of Structural Mechanics and Design, TU Darmstadt (Germany). After his studies in civil engineering in Darmstadt and Coimbra (Portugal), he received his PhD from TU Darmstadt in 2001 in a topic about structural glass design.*
*From 2001-2005 he worked at the engineering office Schlaich, Bergermann and Partner, where he was involved in the structural design of complex steel, glass and concrete structures. In 2006 he was appointed as an authorized sworn expert on glass structures, in 2007 to the position of a professor for structural engineering in Frankfurt and in 2009 to his current position at TU Darmstadt. Since 2011, he is also partner in his engineering office SGS GmbH in Heusenstamm / Frankfurt. Since 2015, he leads the European project group for the preparation of the new Eurocode 11 „Structural Glass".*
*He is specialized in structural mechanics of glass & polymers, façade structures, structural design and synergetic, energy-efficient design of façades and buildings.*

## SCIENTIFIC COMMITTEE

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*Prof. Dr. Anne Beim*

*Prof. Dr.-Ing. Jens Schneider*

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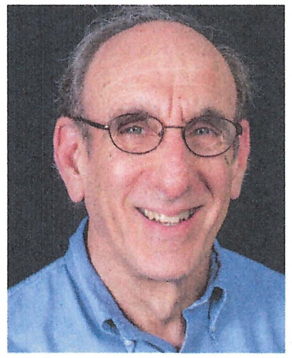


*Prof. Dr. Stephen Selkowitz*

*Prof. Dr.-Ing. Tillmann Klein*

*Prof. Dr.-Ing. Frank Wellershoff*



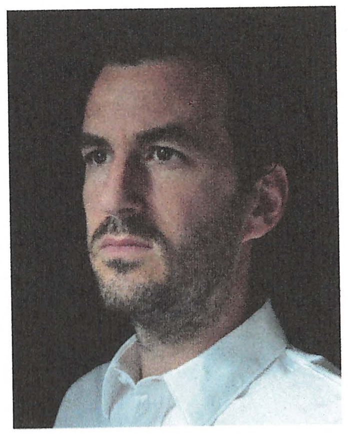
# KEYNOTES

# Achim Menges

## INSTITUTE PROFILE

The Institute for Computational Design (ICD) at the University of Stuttgart was founded in 2008. It is dedicated to the teaching and research of computational design and computer-aided manufacturing processes in architecture. The ICD has received international recognition as particularly innovative research setting and has garnered considerable research funds.
The ICD's goal is to prepare students for the continuing advancement of computational processes in architecture, as they merge the fields of design, engineering, planning and construction.
The interrelation of such topics is exposed as both a technical and intellectual venture of formal, spatial, constructional and ecological potentials.

There are two primary research fields at the ICD: the theoretical and practical development of generative computational design processes, and the integral use of computer-controlled manufacturing processes with a particular focus on robotic fabrication. These topics are examined through the development, specifically, of computational methods which balance the reciprocities of form, material, structure, and environment, and integrate technological advancements in manufacturing for the production of performative material and building systems. The LBNL Windows/Daylighting/Façade team has been exploring these challenges for 40 years, collaborating with researchers, manufacturers, design teams, and building owners globally to move viable solutions into practice. Much of this body of work can be reviewed at http://facades.lbl.gov and over 300 publications can be downloaded from http://eta.lbl.gov/publications



*Achim Menges is a registered architect and professor at the University of Stuttgart, where he is the founding director of the Institute for Computational Design at the University of Stuttgart. In addition, he currently also is Visiting Professor in Architecture at Harvard University's Graduate School of Design. He graduated with honours from the AA School of Architecture in London, where he subsequently taught as Unit and Studio Master in the AA Diploma School and AA Graduate School.*
*Achim Menges practice and research focuses on the development of integrative design processes at the intersection of design computation, biomimetic engineering and robotic manufacturing that enables a performative and sustainable built environment. His institute is an integral part of the DFG Collaborative Research Centre SFB-TRR 141 "Biological Design and Integrative Structures" and the DFG Collaborative Research Centre SFB 1244 "Adaptive Skins and Structures". He has published several books on this work and related fields of design research, and he is the author/coauthor of more than 125 scientific papers and numerous articles. His projects and design research has received many international awards, has been published and exhibited worldwide, and form parts of several renowned museum collections.*

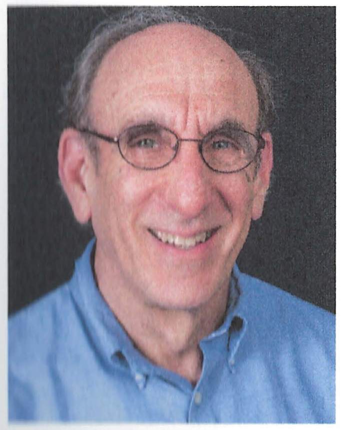


# Stephen Selkowitz

## FUTURE BUILDING SKINS – SMART, ACTIVE AND ADAPTIVE FAÇADE SOLUTIONS

The building skin alternately connects occupants to the pleasures of the external environment and shelters them from its harshest impacts, using materials, systems and energy to actively manage that relationship. Given the dynamics and extremes of the outdoor environment and the changing personal and functional needs of occupants, successful management requires an active and adaptive building skin that senses and responds to changing needs and requirements. This concept is not new, but it is rarely executed effectively since elegant conceptual designs often run afoul of the realities of the physics of heat and light, the frailties of technology, the challenge of budgets and the behaviour of people, typically defaulting to a static compromise solution that rarely satisfies divergent performance needs. In this presentation we look ahead over a 5 to 15 year time horizon to first define a series of idealized, yet achievable trends and solutions, then identify the technologies, systems, tools and processes we would need to realize them and finally explore how to accelerate some promising high performance glazing, shading and daylighting systems options that will deliver these solutions to a range of building applications and markets.

The LBNL Windows/Daylighting/Façade team has been exploring these challenges for 40 years, collaborating with researchers, manufacturers, design teams, and building owners globally to move viable solutions into practice. Much of this body of work can be reviewed at http://facades.lbl.gov and over 300 publications can be downloaded from http://eta.lbl.gov/publications



*Stephen Selkowitz is Senior Advisor for Building Science, Lawrence Berkeley National Laboratory, now in a part-time research and strategic planning role after leading LBNL's building performance teams in research, development, and deployment of energy efficient technologies and sustainable design practices for 40 years. An internationally recognized expert on window technologies, window software tools, façade systems, shading solutions, daylighting, and integrated building systems solutions he created and then led the LBNL Windows and Daylighting Group until 2015. The LBNL team has been instrumental in partnering with industry to introduce new technologies to building markets, e.g. low-e, spectrally selective and electrochromic coatings, and in creating a suite of tools used by researchers, manufacturers and designers globally, e.g. WINDOW, THERM, Optics, Radiance, Energy Plus. He served as Department Head for the LBNL Building Technologies Department for 25 years, partnering with industry to develop and demonstrate new building technologies, systems, processes and tools. He serves as Scientific Advisor to four building science programs globally that address zero net energy building solutions, is employed as a consultant to industry, has spoken at over 400 scientific, business and industry venues and authored over 170 publications, 4 books and holds 2 patents. He holds an AB in Physics from Harvard College and an MFA in Environmental Design from California Institute of the Arts. In 2012 he was the recipient of the first LBNL Lifetime Achievement Award for Societal Impact and in 2014 won McGraw Hill/ENR's prestigious Award of Excellence for "relentlessly working to reduce the carbon footprint of buildings and for moving the nation towards better building performance."*

Guerra-Santin, O., Bosch, H., Budde, P., Konstantinou, T., Boess, S., Klein, T., & Silvester, S. (2016). 2ndSkin approach to zero energy renovation. Paper presented at the BEHAVE 2016, Coibra, Portugal.
ISO7730. (2005). Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria (pp. 60). Geneva: International Organisation for Standarisation
Itard, L., & Meijer, F. (2008). Towards a sustainable Northern European housing stock (Vol. 22). Amsterdam: IOS.
Konstantinou, T., Klein, T., Santin, O. G., Boess, S., & Silvester, S. (2015). AN INTEGRATED DESIGN PROCESS FOR A ZERO-ENERGY REFURBISHMENT PROTOTYPE FOR POST-WAR RESIDENTIAL BUILDINGS IN THE NETHERLANDS. Paper presented at the Smart and Sustainable Built Environment (SASBE) Conference 2015, University of Pretoria, Pretoria, South Africa.
SER. (2013) Energieakkoord voor duurzame groei. Den Haag: SOCIAAL-ECONOMISCHE RAAD.
Sijpheer, N. C., Borsboom, W. A., & Opstelten, I. J. (2016). Results from first "NetZero Energy" projects in the Netherlands. Paper presented at the Sustainable Built Environment 2016: Transition Zero – SBE16, Utrecht. http://www.hu-conferenties.nl/index.php/sbe16/
Silvester, S. (1996). Demonstration projects and energy efficient housing. (PhD PhD), Erasmus University Rotterdam, Rotterdam.
Stroomversnelling. (2013). Maak de stoomversnelling mee. Retrieved 23.11. 2015, from http://www.stroomversnelling.net/over-stroomversnelling/
Voorbeeldwoningen. (2011). Onderzoeksverantwoording. Sittard: Agentschap NL.
Winter, R. e. a. (1993). Evaluatie van het E'novatioprogramma (R. Advise, Trans.). In RIGO (Ed.). Amsterdam: RIGO.
WoON2012. (2013). Energiebesparing: Een samenspel van woning en bewoner - Analy-se van de module Energie WoON 2012. Petten: ECN and RIGO.



# Timber Prototype – High Performance Solid Timber Constructions

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## Abstract

*The paper presents the development of a building system made from solid timber that fulfils the requirements of modern building skins while expanding the design possibilities through innovation in computational design and digital fabrication. The strategy is to augment the comparatively high insulation values of solid timber by cutting longitudinal slits into beams, generating air chambers that further inhibit thermal conductivity. Various configurations of slits and methods of assembly are explored to find the best combination of high insulation values, structural capacity, ease of construction and design variability. A first version of the system is tested at a building component level with digital models and physical laboratory tests. It is further in a prototype building, where blower door tests and infrared imaging are used to identify issues and further refine design, fabrication and assembly methods. Results are integrated into proposals for new methods of implementation. The results of the research thus far demonstrate the validity of the strategy, and continuing research will improve its viability as a building system. The continuation of the project proposes more effective supply chains by partnering with industrial partners to rapidly produce standardized building units and integration of computational design and fabrication techniques that allow the generation of more complex forms through customizable details.*

## Keywords

*solid timber construction, insulation, building physics, digital fabrication, architecture*

# 1 INTRODUCTION: PRINCIPLES OF MONO-MATERIAL CONSTRUCTIONS

Current building and construction industries combine many materials from different origins. This long standing trend follows the logic that, for each specific task, a material can be found which is best suited in terms of the properties, production, construction processes and costs. With this strategy the efficiency and performance of each component can be maximized. Thus, the complexity of each part of the construction and the building as a whole is increased. However, unintended consequences follow from the complexity of hybrid constructions: (1) Despite the efficiency of each element the overall costs can be higher; (2) Maintenance and repairs also become more complicated and expensive; and (3) In addition, recycling and reusing materials and components becomes more difficult (Knaack, Klein, Bilow 2015).

At the same time, a new trend for mono-material constructions can be observed especially in brick buildings. This is supported by research suggesting new numeric models for the energy consumption of buildings, which emphasis the thermal storage capacities over the insulation (Tersluisen & Nasollahi 2016). As a built example for this trend the building of Baumschlager Eberle 2226 in Lustenau can be named, which uses a monolithic brick wall of 76 cm thickness consisting of two different types of bricks (Baunetz Wissen 2016). The building manages to be operated in a convenient temperature range without active heating systems. Other examples can be found in monolithic concrete construction which use ultralight concrete, or 'Infra-Lightweight Concrete', to achieve the necessary insulation (Schlaich & El Zaire 2008). Here, the concrete weight is reduced to 800kg/m3 by adding porous materials. The same approach can be seen in timber construction in the last years, where solid building elements are thermally activated and used as insulation and structure at the same time.

# 2 INTRODUCTION: BUILDING SYSTEM PRINCIPLES OF TIMBER-ONLY CONSTRUCTION

Solid timber has many advantages in comparison to other standard construction materials. Timber requires less energy than concrete or steel for its production (Gordon 2003), which reduces overhead and operating costs of building with wood. As a renewable resource, and given its negative carbon footprint and low embodied energy (Alcorn 1996, Kolb 2008), timber plays a central role in the current discourse on carbon-neutral, energy and resource-efficient construction. The development of new timber construction techniques has focused mainly on hybridization of wood products with other materials to improve the bearing capacity (timber and steel or wood-steel-concrete) and fire protection (timber and gypsum products and wood-concrete). A significant percentage of buildings use so-called structural timber (BSH) or sheet material (esp. OSB or plywood), which consist only partially of actual wood and gain strength from glues and binders (Hegger et al. 2005). Although these hybrid constructions have opened new markets such as the multi-story housing, the permanent binding of very different materials has led to the loss of many of the advantages of timber. With hybrid wood products, separation of the component materials is not economically feasible, and the reduction of carbon dioxide emissions from timber are largely negated by the high emissions of secondary materials such as concrete or steel. Solid timber is much more readily reused, recycled, or consumed as a source of compost or energy. Much of the waste (about 53% in 2012 in Germany) is generated in the construction industry for erecting and refurbishing buildings (Statistisches Bundesamt 2016).



Timber-only systems are therefore an interesting alternative for efficient and sustainable buildings. One notable system is the 'Holz 100' by the Austrian company Thoma (Thoma 2003). This system is based on layering smaller timber profiles in a diagonal pattern. The layers are connected by a regular grid of beech dowels, making the main part of the construction also mono-material. The system achieves a lambda-value of 0,078 w/mK, which is significantly higher than that of solid timber with a lambda-value of 0,13 w/mK for most softwoods. There are other solid timber systems available with similar properties but less material integrity. Limitations of the 'Holz100' systems can be seen in the insulation. In order to comply to the high European energy standards, in this case Passivhaus standard, the 'Woodcube' building in Hamburg was built with a wall construction of 290 mm wood plus 44 mm insulation and a U-value of 0,19 W/m² (Petersen & Redeem 2014). The design of the timber members in the presented research project further develops ideas for contemporary timber-only building systems (Fig. 1).

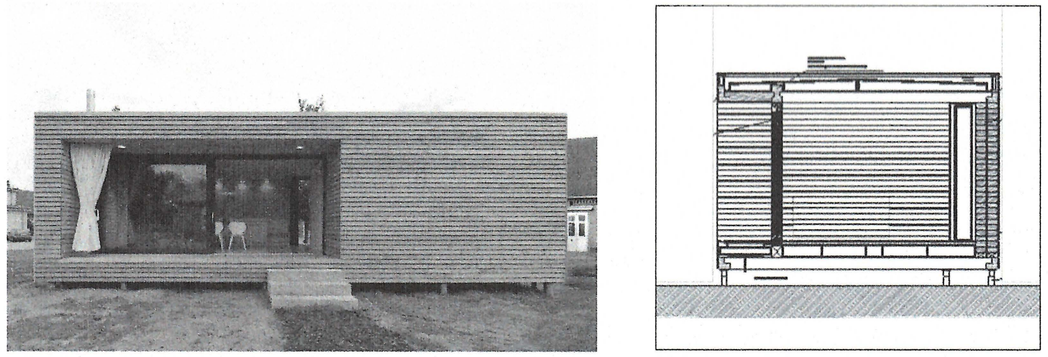

FIG. 1 The first demonstrator building 'Timber Prototype 1' built at the Munster School of Architecture (MSA) evaluating the advantages of timber-only construction systems.

# 3 CONSTRUCTION SYSTEM DEVELOPMENT

The approach of a timber-only construction offers the possibility to integrate insulation and heat storage in a single component (Fig. 2). The results of the research project should culminate in the design of a building system that optimally utilizes the material properties and thus provides a balance of structural performance, insulation and storage capacity. A first demonstrator was built in 2012 in order to evaluate the first iteration of the construction system on a larger scale. The paper also presents further development of the construction system, for which a second demonstrator is currently planned.

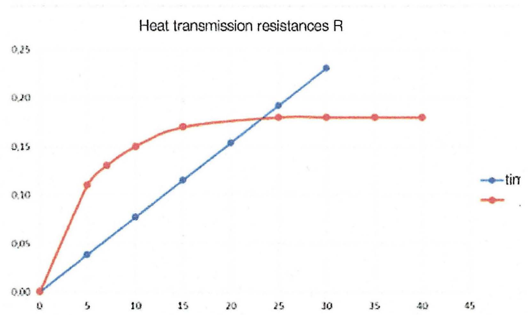


FIG. 2 Heat transmission resistance comparison between solid hardwood and stationary air according to DIN6946-6.

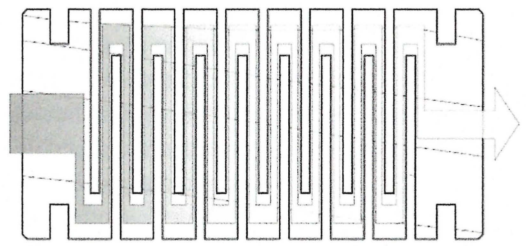

FIG. 3 Thermal transmission of slit timber beam in sectional view

## 3.1 BASIC BUILDING SYSTEM (TP 1)

The traditional timber building method, which stacks solid horizontal members and interlocks them in the corners, provides insufficient insulation for contemporary buildings. Therefore, during the development of the first demonstrator, called 'Timber Prototype 1', the traditional construction was augmented by cutting slits lengthwise into the timber members which produce air cavities (Fig. 3). The intent was to improve the thermal insulation of timber by increasing the air content in the timber members, since air has a lower thermal conductivity than timber. The capacity for insulation depends on the geometry, size and orientation of the air cavities. By carefully calibrating these parameters, the circulation of air (convection) that transports heat energy from the warmer to the cooler side of the cavity could be minimized. Figure 2 suggests that the size of these air cavities should be less than 15 mm in the direction of the heat transmission. Therefore, the hypothesis of the project is that as many slits as possible with the smallest possible volume will create the best insulation values. During the entire project, full scale prototype components (wall, ceiling, roof, floor) are fabricated and tested in both laboratory and onsite.

### 3.1.1 Construction Elements

The construction was developed as a contemporary block construction. Dimensions of vertical and horizontal elements are determined by the required thermal insulation values. Commercially available solid timber beams would not provide the depth required to achieve necessary insulation values. Therefore, the width of the walls, ceiling and floors was increased to a total of 400 mm by using two layers of modified solid timber beams, cut from standard dimension profiles of 200 x 100 mm. The width of air slots is determined by the dimension of the saw blade. The connection between the horizontal layers was secured by a groove and notch system at each end on the profiles. The wall as a whole was constructed using threaded rods with springs, which tighten the layers while allowing the timber elements to shrink and expand when its moisture content changes (Fig. 4).

A structural analysis of the construction was conducted as part of the planning application. Since only 40% of the wood volume has been removed when cutting the slits, the remaining material had enough strength to support vertical elements. For multi-story buildings, the compression orthogonal to the direction of the fibre will likely become a limiting factor. In the first demonstrator built with this construction system, ceiling and floor elements are all made with the same method. However, they do have a load bearing and cross bracing function in the overall structural system. For a single story building the structural forces within all timber members are within load bearing capacity. For horizontal elements (floor and ceiling) ten members were combined into a building component of 100 cm in width.



In order to be able to span between 4,5m and 5,5m each element is equipped with a solid edge beam on either side of the same dimension. The slit timber beams in between were not included for the structural calculation. Their softness proved challenging as the slits reduce the structural integrity, leaving it flexible and compressible. Therefore, in the final construction of the ceiling and floor a secondary layer of OSB 21 mm had to be introduced in order to distribute the loads more evenly into the construction.

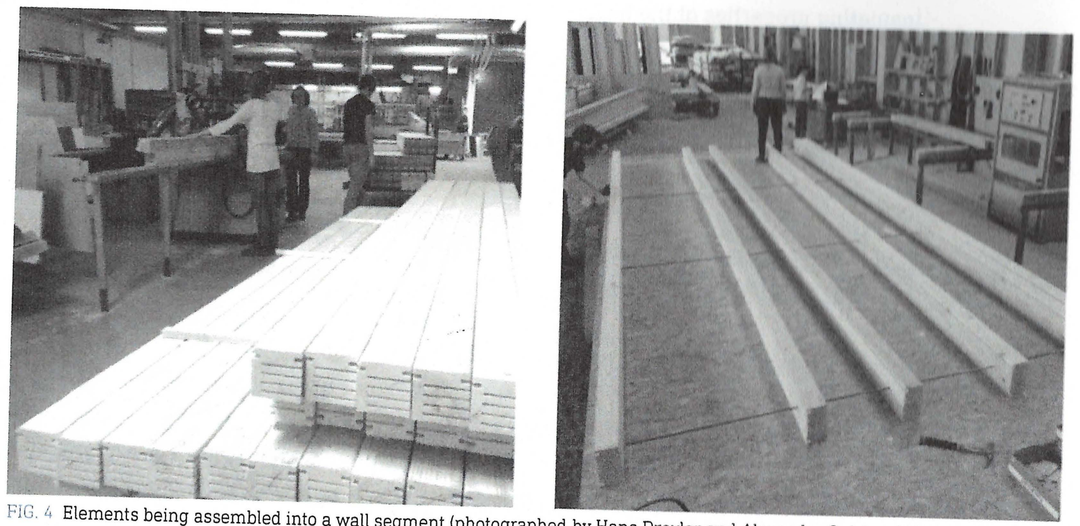

FIG. 4 Elements being assembled into a wall segment (photographed by Hans Drexler and Alexander Quiring, MSA 2012)

### 3.1.2 Fabrication

The timber profiles have been produced on a small milling machine, where four grooves can be cut in parallel. Each of the profiles had to be milled 8 times resulting in a production time of roughly 88 hours for 15300 m of profiles in total (Fig. 5). In the next stage of the project this process will be translated to an industrial production process. Sawmill and moulding factories use large scale machinery with multiple saw blades capable of simultaneously processing both sides at high speeds.

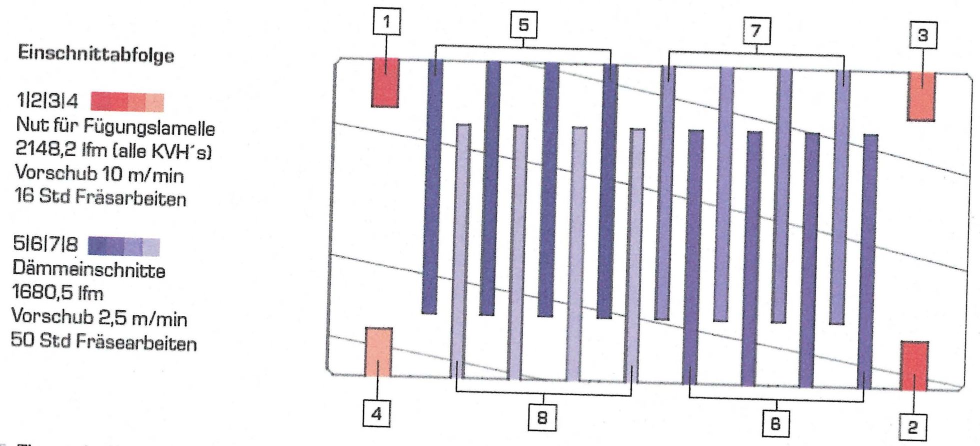


FIG. 5 The production process of timber members for 'Timber Prototype 1' is divided into several steps (Drawing by Rene Stegemann, MSA 2012)

## 3.2 EXTENDED BUILDING SYSTEM

In a second research project the building system will be further developed by taking advantage of the insulation capacity while integrating digital design and fabrication techniques for an extended design space. A second demonstrator is planned to be built in 2017. Given the success of the first demonstrator, the authors aim to develop design systems that take advantage of the proven insulating properties of the technology while expanding formal capabilities in order to demonstrate a broad versatility of practical implementation. This requires a combined effort that creates opportunity for new architectural articulation while optimizing physical performance. Starting with the timber unit developed described in chapter 4.1, the project explores how the individual building unit itself could inform potential formal manipulations.

### 3.2.1 Construction Elements

In order to minimize the joints, and thus, the potential points of air ingress, the further development of the system focuses on the timber beam as a linear block unit. The modules can be rapidly produced as standardized units that are then joined with custom details to generate architectural form. Similar to traditional masonry construction methods, as the units are aggregated, a gradual offset of individual blocks can generate various global geometries. The linearity of the timber unit, when aggregated in such a fashion, generates ruled surface geometries (Fig. 6). This surface can be described by two curves that determine the position of the ends of the linear unit. When these two generator curves are non-parallel, offset lines, the resulting geometric surface is a hyperbolic parabola. However, they can also be free form curves in three dimensional space.

As with traditional ceramic or concrete masonry construction, the system relies on a layer of binding material for structural connection, weather protection and airtightness. For this purpose, a custom layer is developed to create a stable joint that both generates form and structural stability. This comes in the form of a solid wood sheet with a series of raised finger elements that join with the slits in the standard beam unit (Fig. 7). These 'Key Sheets' are generated in computationally derived parametric models and contain the information needed to generate the desired global shape. They serve to stabilize the highly flexible beam units, and, depending on their orientation, may function as beams in horizontal spanning sections. Furthermore, these layers must also generate a seal to resist moisture and air penetration to maximize thermal performance. While the key sheets will be critical to prevent air gaps, it will also be important to minimize prolonged water contact on the exterior surfaces of the structure due to precipitation. A secondary system of overlapping planks is proposed to help shed liquid water from exterior surfaces. These elements will run the length of the primary beams and will integrate with the joinery system.



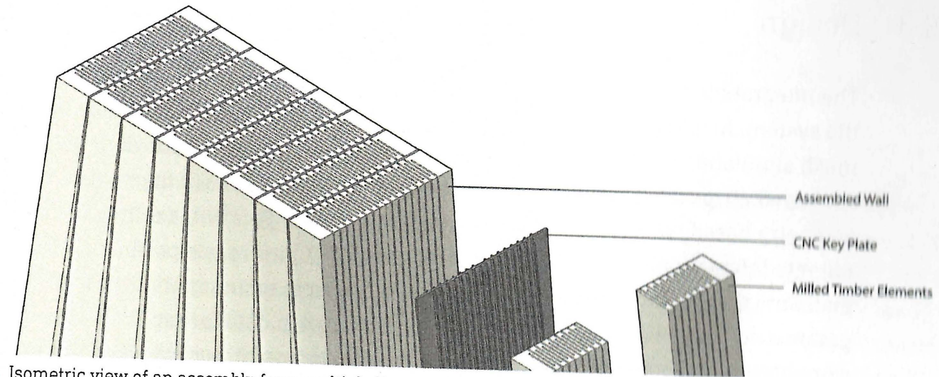


FIG. 6 Isometric view of an assembly from multiple linear units generating a ruled surface geometry

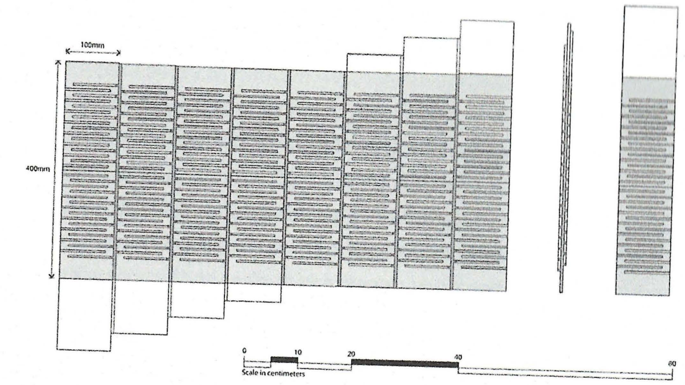

FIG. 7 Sectional top view of the building system, with an exploded view of the key sheet between two layers of linear beams

### 3.2.2 Fabrication

The prototypical production process makes strategic use of the available machining technology in the production of a module. The beams are milled on an industrial scale electric planer with a modified tool head that can simultaneously cut multiple slits. A standard unit size allows all pieces to be rapidly milled on this machine. Beam profiles use a standard cut pattern with regularly spaced strips and leave a solid profile end to accommodate for offsets between adjacent units in the completed wall sections. The key sheet geometry is generated individually through computational models that directly output machine code. They are fabricated on a three-axis CNC mill in a two-sided operation in which each piece is flipped during milling. All pieces are systematically tagged to ensure correct assembly order. Assembly requires significant forces, and requires a series of jigs and clamps to press the various components together into larger building assemblies. The assemblies are limited to transportable dimensions so that the sections can be rapidly assembled onsite.

The first prototype was constrained to an analogue production process which combined manual labour with simple machinery. This experience suggested a division of manufacturing in standardized, repetitive members and detail-dependent individual connections: Through spindle moulders, planers and saws, uniform formations can always be achieved quickly and efficiently while preserving the insulating function. For the production of individual joint geometries CNC-machining methods were evaluated. They allow the production to be cost-effective and flexible.

### 3.2.3 Design

The integration of Computational methods allows for an expansion of the potential design space of the system. In addition to thermodynamic modelling used to predict insulation performance, spring mesh simulation models are used to evaluate physical bending behaviour of beams and to develop the keyed strips used to bind them. Parametric modelling is used to precisely determine resultant geometry based on standard lumber stock dimensions. This helps minimize time and resources put into fabrication through standardization and industrial scale production where appropriate. Elements that require precise and non-standardized machining are developed in the same parametric models that can instantly output fabrication data for rapid prototyping. This integrated, computational process allows for a smooth work process through design, analysis, fabrication and assembly. Multiple factors will be integrated in order to develop computational tools that will aid in the design and fabrication of a second demonstrator building. These factors include building physics, structural capacity, machinability, ease of assembly, cost, formal expression and architectural program. All of these factors are inextricably linked, and will be addresses through custom scripting components that strike an effective balance between formal desires, building performance, and construction realities.

Certain limitations of the building system are established, and will be productive constraints for generation of form. When the beams are aggregated, their orthogonal profile causes the ruled surface geometry to require a strong linear orientation. The simplest solution is to maintain a relatively linear orientation of the building assemblies, which will require relatively simple modular joints between sections. If it becomes necessary to change the axis along which beams are oriented, corner details must be developed that can accommodate complex angled interfaces between units. Beams offsets used to generate ruled surfaces must be minimized as they effectively decrease the total wall thickness by double the offset amount, which would greatly reduce insulation values. Surfaces that are likely to receive large water loads must have a protective water shedding layer, which means that the underlying beams should not cross along their length, which would force the overlap to switch orientation, creating a weak point in the waterproofing. In addition, beams should not be completely horizontal to prevent pooling of water. These are just a few of the main constraints that will inform the algorithmic processes by which form is generated.

### 3.2.4 Structural Performance

A key improvement of the new building system is the general orientation of all building elements in accordance to the main load bearing direction. In the ruled surface geometries of the wall elements, the main fibre direction is vertical. On a local level, the loads can be transferred along the fibre direction and therefore make efficient use of the material capacity. On a global level, ruled surface geometries are structurally more stable due to their curved connection to roof or floor elements. The usually three-dimensional curve describing the edge between horizontal and vertical elements is mostly experiencing tension and compression loads, compared to straight edges that have to be designed for high bending moments. The global depth that results from the ruled surface geometry also cross-braces the wall elements.



# 4 BUILDING PHYSICS EVALUATION

## 4.1 THERMAL INSULATION

In a first step, the thermal properties of the first iteration of the building system used in the demonstrator 'Timber Prototype 1' were modelled with the heat requirement calculation programme URSA V3.2.0.0. In a second step, the thermal properties were examined and compared to the thermal properties of solid timber block construction. A digital model of a simple flat roof building in the dimensions 3000 mm x 9000 mm x 3000 mm was modelled with the heat requirement calculation programme ZUB Helena Ultra v7.43. The results were found to be consistent with the calculations from the first step. The aim was to determine the thermal transfer coefficients (U-values) of the walls, floor plate and flat roof separately and whether such a small building as a whole would fulfil German energy efficiency standards as regulated by the German Energy Efficiency Decree (Energieeinsparverordnung 2014, or EnEV2014, based on European standards).

In order to achieve the necessary insulation, two layers of timber each 20 cm in width had to be combined. For water protection, a ventilated timber façade was also added. This improved the U-value significantly from 0,281 W/m2K for a wall construction of 44cm solid timber to 0,206 W/m2K.

The thermal transmittance of each variation was compared to the thermal transmittance of a continuous timber construction and to the U-value used for the reference building according to EnEV2014 (Table 1). For simplicity, external wall constructions only are shown here.

| CONSTRUCTION TYPE | | WITH NON-VENTILATED AIR CHAMBERS | | | | |
|---|---|---|---|---|---|---|
| Wall construction type | Reference building EnEV2014 | Insulated vertically perforated brick (1) | Timber frame construction (2) | Solid timber | TP1 | TP1 Min (3) |
| Thickness in mm | n.a. | 330 | 162 | 440 | 446 | 320 |
| U-value in W/m²K | 0.28 | 0.253 | 0.274 | 0.281 | 0.211 | 0.270 |
| # of air cavities | n.a. | n.a. | n.a. | n.a. | 28 | 20 |

TABLE 1 Wall construction types compared to variations the developed building system.

1) *Wall construction (from inside to outside): 10 mm plaster, 300 mm vertically perforated brick with insulated cavities, 20 mm plaster*
2) *WWall construction (from inside to outside): 9.5 mm plasterboard, 12.5 mm OSB, 100 mm timber frame construction with rock wool insulation (0.035 W/mK), 40 mm softboard*
3) *Minimum thickness to fulfil German Energy Efficiency Decree for the above described non-residential building*

Furthermore, the minimum thickness of 'Timber Prototype I' to achieve a U-value of 0,28 W/m²K was determined. A minimum of 10 air chambers per beam are necessary, with 3 mm thick air chambers and 7 mm thick timber layers between chambers. The minimum thickness of the wall amounts to 320 mm. Calculating with non-ventilated air chambers, the wall may be 27% thinner than a continuous timber beam wall. Four further variations of the same structural compositions but with ventilated air chambers with a slow air flow were modelled. When a slow air flow is allowed for, the resulting U-values at the same construction thickness are approx. 22% higher. The minimum number of air chambers necessary to fulfil German energy efficiency regulations increases from 10 to 13. Additionally, without glue joints or other air proof connections between timber layers, the air chambers are likely not to be airtight. This may result in reduced thermal performance, even though convection in such narrow cavities is likely to be reduced. Further research on the air tightness of the construction system will be necessary.

For the roof and floor the insulation had to be improved due to the requirements in German Energy-efficiency Regulations for Buildings (EnEV 2009, limited to U = 0,20 W/m²K), which could have been achieved by the system. Due to the shape of the building with a large roof and floor area, the overall heat demand is largely determined by these components. The calculations indicated that in order to achieve the required insulation values, a third layer of the insulation timber could be added, resulting in a height of 60cm for the floor and roof. Instead, in 'Timber Prototype I', a more efficient cellulose derived insulation was added. The main advantage was that this layer could also be used to generate the necessary roof incline.

## 5 AIR TIGHTNESS

A central problem of all block constructions is air tightness. Layering single members leads to significantly more horizontal joints than in a timber-frame construction with continuous cladding and sealed joints or in brick walls, where air tightness is achieved by mortar and a continuous layer of plaster usually on the interior wall surface. In traditional and modern block constructions this problem has been addressed by introducing more or less complex tongue and groove joints between the layers. In the first demonstrator a 'BlowerDoor' test was conducted to test the air tightness of the building and detect leakages. The average measured air change per hour at 50Pa pressure difference was 6,2 1/h. However, the building was insufficiently air tight due to a variety of factors: Connection details on site were executed by students, lacking professional construction experience. Irrespective of the construction system, significant air leakages were detected on the opening joints of the large scale sliding windows and the air duct lead-in from the heat pump. The decentralized ventilation systems were sealed with masking tape, but air passed underneath into the wall construction. The same phenomenon occurred around the exhaust pipe of the wood burner.

### 5.1 MOISTURE PROTECTION

A challenge of the building system in the first demonstrator was rain and wind on the outer surface of the walls due to the horizontality of the joints. When joints are not perfectly sealed water will penetrate the horizontal joints and accumulate in the cavities. The ingress of water due to strong rain and wind is difficult to predict. Liquid water inside the timber construction quickly causes decay, fungal infestation, and irreversible damage. Therefore, moisture protection has the highest priority in timber construction. In the case of the 'Timber Prototype 1' the inner wall construction was protected by an additional ventilated timber facade. With respect to simplicity and a higher level of integrity it would be best if the additional facade became unnecessary. Different designs have been studied that would include an overlapping dripping edge in the shape of the outer profiles. This has not been implemented in the first demonstrator because of the high volume of wood that would have been removed to achieved the dripping edge.



## 6 CONCLUSION

While the first demonstrator 'Timber Prototype 1' evaluated the principle building physics as well as the structural integrity of the building system, the continuing development is focused on the possibilities of digital design and fabrication. Current digital technologies enable the exploration of an extended design space within the constraints of German energy efficiency standards. The building physic evaluation of the first demonstrator indicate that the necessary insulation for a contemporary building is not in opposition to a higher level of architectural expression. Most importantly, the innovative design allows to integrate the structural and constructive performance into the system. In the newly developed building system, connections between the individual timber members as well as larger assemblies can be achieved without the need for metal connectors. As a result, a construction method will be developed, which has the potential of being a mono-material timber construction and at the same time achieving an integral solution for the physical and structural performance of a contemporary building skin.

## 7 OUTLOOK

An ongoing discussion within the research team is addressing the transferability of the building system for more conventional building typologies. Planar building elements and orthogonal constructions are far more common than curved geometries. The main advantage of the newly developed building system is seen in its adaptability. Through the parametrically adapted key sheets between each layer of slit beams, wall elements can be curved but also straight and planar. However, it is worth noting that one of the main advantages of the system - its stiffness and self-stabilizing cross-bracing - can only be achieved with a more complex double curved geometry. Using the system for a planar geometry will make it necessary to introduce more powerful joints between the elements and additional cross-bracing.

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**References**

Alcorn, A. (1996). Embodied Energy Coefficients of Building Materials. Wellington: Centre for Building Performance Research, Victoria University of Wellington.
Baunetz (2016), Bürohaus 2226 in Lustenau, http://www.baunetzwissen.de/objektartikel/Mauerwerk-Buerohaus-2226-in-Lustenau_3421609.html (accessed on 31.10.2016)
EnEV2014 (2014). Energieeinsparverordnung 2014, German Energy Efficiency Decree 2014, non-official reading version of the 2. Decree for the Alteration of the German Energy Efficiency Decree, 16th of October 2013.
Gordon, J.E. (2003). Structures: Or Why Things Don't Fall Down. Cambridge: DaCapo Press.
Hegger, M., Auch-Schwelk, V., Fuchs, M., Rosenkranz, T. (2005). Construction Materials Manual. Berlin: Birkhäuser.
Knaack, U., Klein, T., Bilow, M. (2015). Imagine No. 08: Concretable. Rotterdam: nai010 publishers.
Kolb, J. (2008). Systems in Timber Engineering: Load-Bearing Structures and Component Layers. Basel: Birkhäuser.
Petersen, J.-P., Redeem, C. (2014). Smart Material House WOODCUBE. Internationale Bauausstellung Hamburg.
Schlaich, M. & El Zaire, M. (2008). Infraleichtbeton, in Beton- und Stahlbetonbau 04/2008, Berlin.
Statistisches Bundesamt (2016). Bau- und Abbruchabfälle 2016, https://www.destatis.de/DE/ZahlenFakten/GesamtwirtschaftUmwelt/Umwelt/UmweltstatistischeErhebungen/Abfallwirtschaft/Tabellen/TabellenAbfallbilanzKurzuebersicht.html (accessed on 31.10.2016)
Tersluisen, A. & Nasrollahi, K. (2016). Untersuchung zeitgemäßer, monolithischer Wandaufbauten hinsichtlich bauphysikalischer, ökologischer und ökonomischer Eigenschaften. Forschungsprojekt SWD 10.08.18.7-15.34, Technische Universität Kaiserslautern.

Thoma, E. (2008). Vollholz Häuser: Das Baum-Prinzip für naturnahes Wohnen. Wien: Brandstätter Verlag.

ZUB Helena Ultra v7.43 Heat requirement calculation programme based on DIN V 18599, developed by Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V., Fraunhofer-Institut für Bauphysik, Nobelstrasse 12, 70569 Stuttgart.

Software URSA U-Wert, URSA Deutschland GmbH, D-04509 Delitzsch; U-Wert according to EnEV 2009 and DIN EN ISO 6946; Condensation assessment (Glaser-Method) nach DIN 4108-3; http://www.ursa.de/de-de/verarbeiter/seiten/software.aspx




# Powerskin – Fully Fashioned*


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## Abstract

*"Powerskin - Fully Fashioned" is about lightweight design and new textile based building skins. Fully fashioned refers to a textile production technology wherein all parts of a piece of cloth are produced in one integrated production process, ready to wear the moment they leave the machine. Fully fashioned powerskin in an architectural sense implies a light, highly prefabricated textile envelope with minimum needs of installation work on the building site. It can be used for façade construction in terms of modules as well as for temporary housing structures as a whole.*

*To develop these new textile powerskins, experimental student works and applied research projects at Frankfurt University of Applied Science investigate the potential of the combination of textile technologies with foaming technologies. This paper focuses on so called spacer fabrics and a research project called 3dTEX and founded by Zukunf Bau, where wall elements from foamed spacer fabrics presently are under development. The aim of the paper is to present 3dTEX within the context of the accompanying experimental student design works and to show the so far achieved results for a prefabricated, lightweight, self supporting and highly insulated foamed textile skin, with reduced needs of installation work on the buildig site. This has been achieved by using the spacer fabric as lost formwork and using 3d-textile technologies, so as woven or warp-knitted spacer fabrics, in order to receive complex geometrical sandwich-like textiles. Together with the foam they become FabricFoam©. The new selfsupporting building elements not only offer possibilities for complex architectonical geometries including loadbearing structures, but also a wide range of surface designs in terms of structures, colours and additional functionalities. The focus of 3dTEX is on the development of appropriate textile geometries for one ore twolayer textil elments - depending on the choosen textile technologies. Foamed, they become light-weight, insulated elements, where the two layer textile can even be transformed into a ready-made, rear-ventilated, insulated wall element made from gradient fibre and foam material, able to absorb tensile and compressive forces at the same time.*

*The challenge for 3dTEX is to close the knowledge gap about what kind of of textile technologie can produce the envisioned textile geometriy with which kind of fibre material. Further, 3dTEX research is about the appropriate, possibly in-situ, foaming technologie and foam material , so that fibre and foam materials match in terms of mechanical and building physics as well as in terms of grey energy and recycling aspects.*



## Keywords

*lightweight design, prefabricated textile envelope, façade construction, temporary housing, foamed spacer fabrics, FabricFoam©*



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