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CASE STUDY

Prototypical approach for an individualized standardization process in the context of intelligent construction and automation

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Abstract
Strategies based on an optimal balance between standardization and individualization must be implemented to successfully overcome the current low level of automation in building construction. Project-specific adaptability can be ensured by a combination of automated machine technology and digital planning tools available today. In addition to achieving economic advantages, the focus is on improving sustainability factors, which concern both material consumption and functionality and improved use of resources and energy for building production and operation. The results of research into "lightweight aerogel concrete technology" has shown that an innovative liquid material mixture with insulating properties can be successfully implemented in an automated production process. An adaptive system for standardized wall, ceiling, and floor panels was developed, which can adapt to specific functionality needs and thus address the requirements of individual building tasks while keeping economic as well as architectural factors in mind. The advanced mono-material complies with current European regulations for insulated wall structures, considering the requirements for load-bearing capacity. Due to its homogeneous insulation effect across the entire element section, the aero lightweight concrete allows for intelligent detailing and connection principles and prevents the formation of thermal bridges. The relationship between material composition, material production, construction method, and building operation is essential for a circular planning process. Robotization as a multiple fabrication technology may facilitate these parameters in one cycle. The new technology allows for the crucial transition from research to an end-to-end construction workflow that maps the entire process chain, from concept planning to design and joining principles up to fabrication and assembly.

Keywords Individualized standardization · Adaptability · Lightweight aerogel concrete technology · Resource optimization

Context and relevance

Background and delimitation of serial production for housing/ residential construction

To challenge current planning concepts and respond to the urgent need for housing, methods and approaches in architecture and the building segment must adapt to new ways of building construction. According to the expected further increase in demand for housing, the German government declared its goal to build about 1.5 million apartments in the coming years as part of the Housing Summit in September 2018 [1]. Especially in residential construction, the introduction of serial production determines the production of buildings [2]. Programs driven by the federal government promote the use of serial construction methods. In addition to economic advantages, they simultaneously focus on improving sustainability factors, which concern both material consumption and improved use of resources and energy for building production (construction) and operation. The correlation between material composition, material production, construction method (intelligent construction), and building operation (automation) is crucial for a circular planning process.

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Process design against the background of individualized standardization principles

Sustainability efforts based on a holistic planning approach

Holistic planning strategies provide an integral basis for sustainable and ecologically driven building development. Interlinking and correlating the complex relationships and specific requirements of a planning task identifies the influencing factors to drive processes towards a future-oriented building development.

In this respect, it becomes clear that no planning method and no building material can be implemented or used without restrictions. However, by carefully weighing individual criteria and linking relevant parameters appropriately, a building development can be advanced according to its requirements and environmentally sound.

In addition to an integral planning development, implementing manufacturing methods that enable the digital transfer from planning to automated production reveals an important component and fosters efficient building realization.

Next to intelligent manufacturing methods, holistic planning must focus on material consumption and, therefore, material functionality to reduce the depletion of raw material resources and facilitate recyclability.

Capability of individualized standardization in the context of an adaptable production technology

Currently, available systems for prefabricated concrete modules often show a low degree of automation [3]. Although factory production generates synergies and profitability, manufacturing processes are tied to traditional working steps that still must be accompanied by manpower. In general, a formwork, fixed by its nature and geometry, is used to produce an element. Even though the casing can be reused and the component can be duplicated, the process bares expense in the use of human resources and limitations in flexibility that can only be overcome by an interlocking strategy.

In theory, there seems to be no need for modular standardization because innovations in automated production, especially through the use of robotic manufacturing methods, enable a generally efficient and fully customized production of building elements. However, when taking into account the efficiency of production processes and a construction industry that is not profitable, not every construction task can be solved individually. Prefabrication of concrete components in a factory environment, in particular, offers great potential for increased cost-effectiveness. On the other hand, precast building systems reach their limits in terms of design flexibility because of their reduced variability. The resulting buildings often appear repetitive and monotonous. In this context, the implementation of an adaptive but systematized approach seems purposeful to a) overcome the restrictions and limitations of a closed modular system and b) to meet the current challenges in construction.

Based on our research findings, the most successful approach is to find an optimum balance of standardization and individualization. Optimum balance here means to identify a process in which a high variance of parts and components is achieved in the most efficient manner possible by exploiting automated production technologies. The prototypical research aimed at creating a serial production process with the possibility of individualized standardization. The differentiation from the current state of the art is that a predefined panel's dimensions, for example, can be adapted to project-specific requirements. In addition, the component thickness can be varied depending on the material matrix, and thus the strength and physical properties can be adapted. In terms of design, the surface texture (relief) and coloration can also be individually adjusted. Therefore, project-specific adaptability is understood as the possibility of modifying a design principle or a production process in such a way that the system itself remains the same, but dimensions or layers of components can be scaled, or material compositions can be adjusted. This individual adaptation and project-specific customization can be achieved with currently available automated machine technology connected to digital planning tools. In this way, an adaptive system will grow according to its functions and thus address individual requirements of a building task while keeping economic factors in mind.

Serially-produced precast components based on a digital design process and automated manufacturing

"Aerogel technology"

As a cooperation between TU Dortmund University – junior professorship REB/chair of building construction – and industrial partner G.tecz Engineering GmbH, the research project "Aerogel – Development of hybrid concrete elements with aerated concrete core" aimed to develop a systematized construction method based on a new concrete technology and an innovative production process with possible added functionality, in this case, higher insulation values. Geared towards the development of a market-ready product, the approach pursues a systematized and cost-effective solution to be applied particularly in the affordable housing or office construction segment.

The resulting development ties three significant drivers and frames the research achievement on the triad of production, construction, and digital design. Against this background, the individual fields of material technology, architecture (systematized construction), and automated production have been developed closely and simultaneously with reciprocal effects. Synchronous optimization of all three levels enables the realization of a sustainable product considering the entire life cycle (Fig. 1).

The developed (wall) components as a major part of the system consist of two nano-optimized Ultra High Performance Concrete (UHPC) face layers and a highly insulating, load-bearing lightweight concrete core. Incorporating the novel hybrid concrete material into an automated continuous manufacturing process enables efficient production, assembly, and installation of the story-high multifunctional concrete panels, meeting the versatile requirements of a high-performance and recyclable building component (Fig. 2).

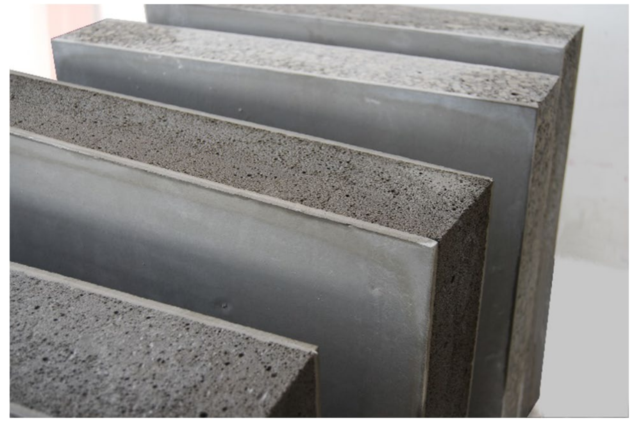


Fig. 2 Prototypical production and dimensioning of wall panels with varying material composition and thickness of the UHPC cover layers. © G.tecz Engineering GmbH

State of the art of automated production methods for monolithic constructions

Its fluid material properties during casting make concrete ideally suited for an automated manufacturing process, and this automation increases productivity in the construction industry. In addition to the inherent design quality of concrete in terms of freedom of form, this shapeability combined with the use of a mono-material in automated production facilitates project-specific adaptation of an otherwise systemized solution. The interdisciplinary research program (Sonderforschungsbereich DFG) "SPP 2187 Adaptive modularized constructions made in flux" focuses on the development of partially adaptive modules, which are integrated into an automated flow production process [4]. Its aim is to develop the basic scientific methods for producing such modules made of high-performance concrete.

Due to new developments at the material level, current construction methods combined with a mono-material matrix, possibly including added functionality, offer great potential regarding sustainability requirements as well as recyclability parameters. Therefore, an innovative material composition has been developed to produce insulating monolithic wall panels. The new material mix (Fig. 3) significantly improves the heat-transmission properties of structural components, which means that more slender element cross-sections and, therefore, weight reduction and less material consumption can be achieved. The component build-up makes an additional insulation layer redundant. Because of the consistency and the specific ingredients, the composition provides insulating properties itself. In comparison to composite building materials,

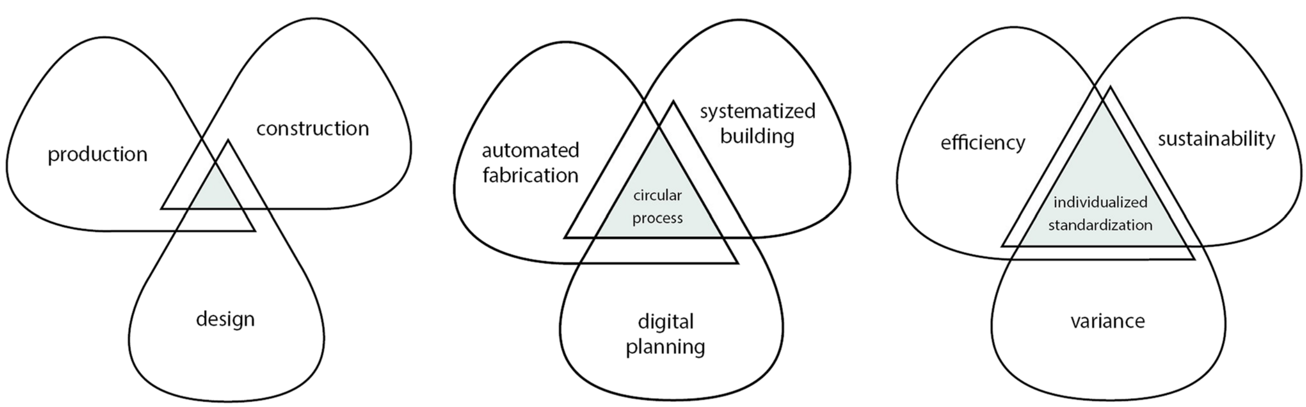


Fig. 1 A. Research concept that fosters the correlation of the main drivers architecture, construction method, and production process. B. Linking the main drivers as part of an innovative planning method. C. Depiction of the goals against the background of a new strategy (individualized standardization) © TU Dortmund

aerated concrete components guarantee a beneficial life cycle and offer greater potential than traditional additive construction methods generally executed as multi-layer build-ups. The multiple advantages on the constructive, economic as well as ecological levels have been examined by A. Tersluisen et al [5].

Against this background, production methods have to be identified that allow for efficient material processing and combine a wide variety of functions in one process. The mono-material approach is highly suitable for additive manufacturing technologies, and 3D printing, in particular. Claypool, Jimenez Garcia, Retsin, and Soler describe the decisive advantage of 3D printing as the combination of different parts and functions within one process approach. The revolutionary aspect of 3D printing is that it enables a new type of continuous assembly principle, away from component-related assembly. Automated control of a specific material matrix allows for highly complex individual geometries to be created without the need for formwork with the same effort as identical components [6]. This creates the basis for individualized production/individualized standardization.

Currently, a reciprocal deficiency between material innovation and automated production processes can be identified. While aerated or insulating concrete is often realized traditionally and in-situ, automated production technologies have been applied only occasionally so far. The current use of 3D concrete printing focuses on the manufacturing technology and on the degree of automation but still lacks the material impact. Additive manufacturing technologies, in general, are rarely used to produce insulating /aerated concrete constructions and have only been researched in a few isolated cases.

The following chapter describes the results of research into suitable production processes, taking technological, constructive, building physical, and sustainability aspects into account.

Fig. 3 Highly insulating material matrix © G.tecz Engineering GmbH

Material development of an aerated concrete mixture with regards to technological and ecological factors

Benefits of the aerogel lightweight concrete technology

In principle, two process sequences are available that lend themselves to producing building components made of a lightweight aero concrete material: the co-extrusion process and the 3D printing technology, or a mixture of both. An extrusion process for the 3D printing technology was developed at TU Dresden in the CONPrint3D-Ultralight® project. That research proved the potential of formwork-free concrete manufacturing in the factory [7].

For the aerogel research project referred to in this paper, a machine technology was developed to specifically exploit the benefits of the new material matrix.

The criteria considered in developing the new technology included:

- Horizontally layered co-extrusion process with adjustable casting instead of vertical 3D extrusion-based printing process without casting.
- Suitable machinery and rapid-curing material composition to ensure high-speed production of wall panels in endless processing.
- Being able to handle significantly reduced element thickness
- Capability to produce multi-layered wall cross-sections of UHPC face layer, foamed concrete core, and UHPC top layer.

Intended to work as a mobile production line, the invented production machinery is stored in standard oversea containers. This allows for highly flexible production close to virtually any building site without local restrictions. Based on an automated endless extrusion process, the standardized wall, ceiling, and floor panels can be efficiently produced using a completely automated process. New types of production and mixing tools were implemented in the manufacturing process to accommodate the high aerogel content. The modular production unit for continuous manufacturing of wall or facade panels achieves a high serial production factor and enables the production of a customized mass component. Due to the integration of a ‘production core’, which contains a specifically developed mixing module, cost-intensive post-treatment of the elements, e.g. passage through an autoclave, can be skipped.

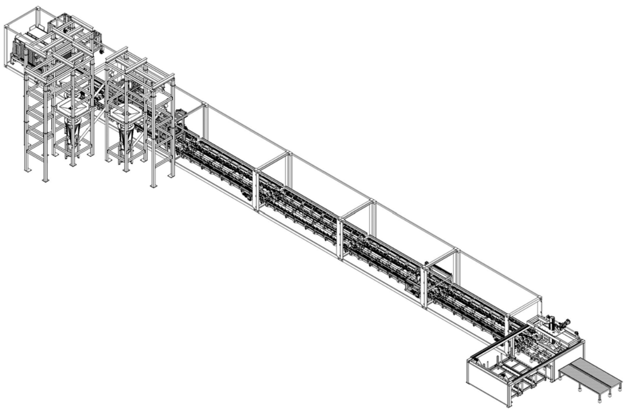


Fig. 4 Mobile production line with integrated mixing modules © G.tecz Engineering GmbH

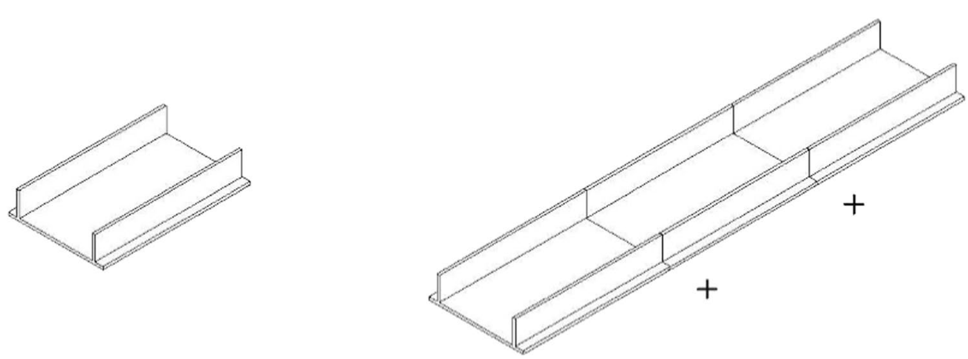
Fig. 5 Mobile machine equipment showing the conveyor belt production © G.tecz Engineering GmbH

The machinery consists of concrete formworks arranged on a continuous conveyor belt with an open top side. The aero lightweight concrete is fed from above via a special mixing module and can be combined with other concretes, e.g. UHPC or High Performance Concrete (HPC) (Figs. 4 and 5).

The production machine adapts the panel geometry in all three dimensions—length, width, and depth with an adjustable formwork, according to the digitized information extracted from the design concept, building physics, and construction method. Moreover, the material thickness can be changed during the co-extrusion/extortion process. Magnetic contacts are used to line up the formwork elements in a continuous loop. After material layering is finalized, components are cut out automatically, which is only made possible by the specific material consistency. This process allows for immediate application of the different layers in a wet-on-wet process. Variability also exists in the synchronization of material consistency. Each material is linked to a specific blending unit integrated into the extrusion-mould process, which can be operated automatically according to specific needs. With a production velocity of 1 m/sec and a panel width of 1,4 m, a production quantity of 84sqm can be produced within one hour (plug-and-produce technology). Each panel or component is labelled with a radio-frequency-identification (RFID) code to allow for smart logistics throughout the entire life cycle. After only 15 min, the aero lightweight concrete is solid due to fast curing and can be removed from the formwork. This production process, however, requires a very high degree of automation and coordination of the material flow (Figs. 6 and 7).

The intended process optimization was achieved. The combination of the new machinery and the specific, rapid-curing material composition facilitates very fast production. The material composition of the lightweight foamed concrete aggregates and aerogel components contributes to a significant reduction in element thickness and thus reduced and optimized cement consumption. The multi-layered wall cross-section of UHPC face layer, foamed concrete core, and UHPC top layer generates a surface-ready exposed concrete quality. The structural joining of aerogel components remains the same for each building design. However, with the new process technology, module dimensions can vary and be adjusted to suit a specific project. At the same time, the technology allows for on-site assembly, and supports high-quality material processing.

Fig. 6 Couplable formwork elements, adjustable for module width and panel thickness



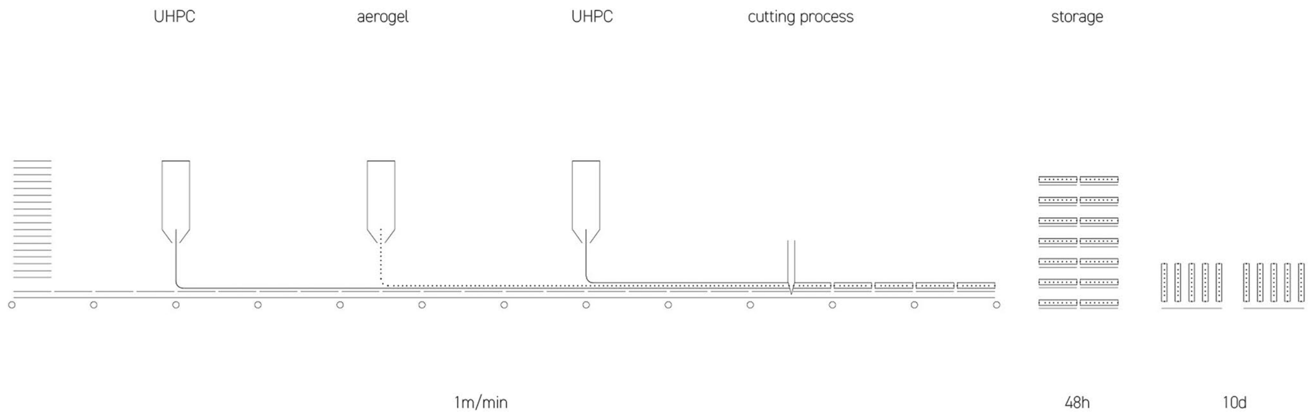


Fig. 7 Horizontal three-layered extrusion process

State of the art material composition and assembly

New material concepts need to be established considering dwindling resources and increasing CO2 emissions that require energy savings on a broader level. Due to their load-bearing qualities, good fire protection performance, and sound insulation properties, concrete constructions are of relevance for the building segment. However, the existing shortage of raw materials requires us to implement novel resource-saving strategies:

1. Maximum reduction of mass and, therefore, reduction of raw material consumption counts as the overriding principle. Since concrete constructions are often over-dimensioned, it is essential to critically examine current dimensions, aiming at optimized element sections. By developing functionally optimized modules, building materials are used according to their specific requirements.
2. In the short term, concrete materials must consist of recycled ingredients to the maximum possible amount. In the medium term, certain raw materials, such as limitedly available cement, must urgently be substituted. Here, the cement industry reveals initial research approaches.

'Lightweight aerogel concrete': Specific material matrix for a modular precast-wall system

The economic and ecological modular precast components resulting from the research referred to in this paper are made of an optimized aerogel content with lightweight aggregates (expanded glass) and foamed concrete on a UHPC adhesive base called 'lightweight aerogel concrete' (Fig. 8). One of the product and process development innovations was to consider and control the hydrophobic properties of aerogel with the standard ingredients of a concrete mix. The inherent conflict in properties is aggravated in the development of foamed concrete compared to regular concrete. The foam-forming admixtures, aerogel and lightweight aggregates interact due to the demand for water and the mechanical effects in the production process. They directly influence the density, flowability, and ultimately the strength of the concrete. The concomitant objective of the development was to increase the share of aerogel to ensure the economic efficiency of the product.

The final material composition achieves the required thermal conductivity of 0.088 W/mK at a compressive strength of 1.75 MPa. The advanced mono-material meets the current European regulation standards for wall insulation and simultaneously incorporates the structural or load-bearing demands. A thickness of 36 cm is required to maintain the maximum permissible heat-transmission value of 0.24 W/(m2K) for wall components. Additional work processes needed in traditional building technologies can be completely eliminated (Table 1).

Fig. 8 Material sample of the 'lightweight aero concrete' mixture. The hybrid component shows the outer UHPC layer and the lightweight porous core © G.tecz Engineering GmbH

Table 1 Properties of aero concrete matrix

Density	550 kg/m3
Compressive strength	1.75 N/mm2 (after 7 days)
Rapid concrete*)	0.67 N/mm2 (after 15 min) 1 N/mm2 (after 60 min)
Lambda	0.088 W/mK
Wall thickness	36 cm according to EnEV 2019**)

*) Based on a different raw material selection and lightweight aero concrete recipe

**) Energieeinsparverordnung für Gebäude

The 'optimal' lightweight aero concrete matrix determined in the project has the following properties (Fig. 9):

Sustainability aspects

Currently, the research project maps an automated extrusion process. However, it is assumed that the addition of robotic process technology, for example, to enable the insertion of assembly anchors, the insertion of elements to form a reversible joining technique or to enable post-processing of the panels, would lead to a higher degree of automation and an increase in productivity. With this, strategies and methods for a more individualized yet ecologically and economically driven building process will be generated. Considering the described challenges, planners must tackle and perceive the new means of robotic manufacturing as an opportunity to merge new material technologies and available planning tools.

Based on a mono-material, the closed-loop system has been developed regarding very high sustainability factors validating the reduction of raw materials, energy consumption, and excellent performance regarding maintenance and recycling. Due to its hybrid layering structure of a high-strength aerophobic surface layer and an insulating aerogel foam concrete core, the lightweight aero concrete contributes to a significant reduction in material usage. So, on the one hand, a reduction in the use of resources is achieved by reducing the mass of the components. On the other hand, reusing recycled concrete (RC) components within the concrete matrix means that less virgin material is required. The energy consumption during the production process is reduced by a factor of 3, while at the same time, the CO_2 balance for material production is improved by using recycled materials. Based on the results of cooperating partner Gtecz Engineering and according to the results of other experts such as Müller et al., the use of recycled concrete components is target-oriented [8]. Further research needs to be conducted to investigate whether the permitted maximum of 30 RC components per 100% concrete demolition can be integrated into the innovative material matrix used for load-bearing concrete components.

Furthermore, sustainability criteria will be improved easily by integrating on-site automation. The mobile production line allows for true on-site production, the use of about 90% local raw materials, and optimized logistics.

The highly resistant façade material ensures a very long life cycle, providing a durable and solid construction. Due to the water-resistant and dense UHPC surface, maintenance costs are reduced. Material recycling is

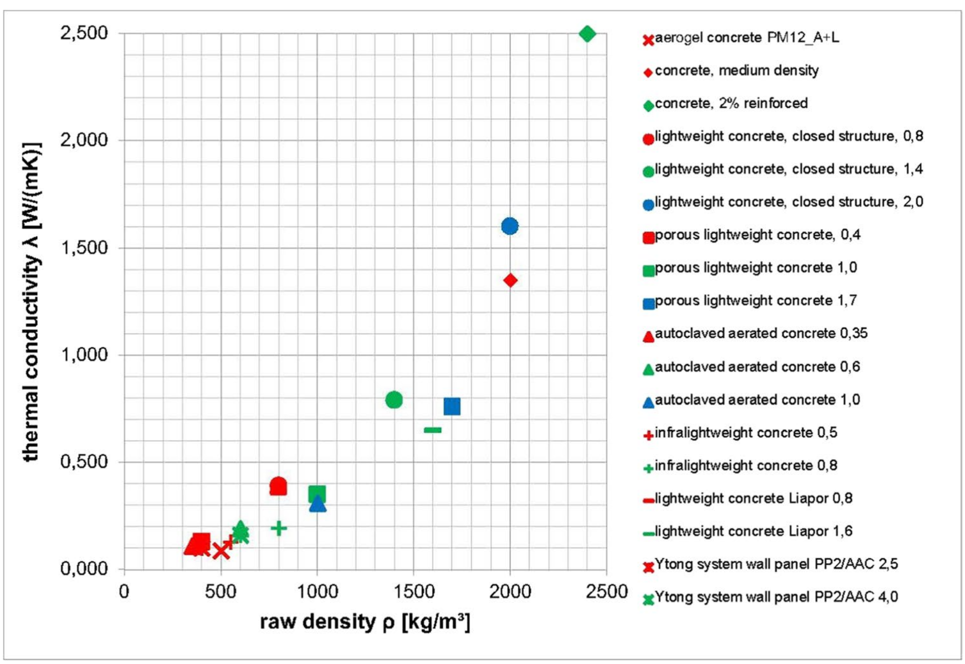


Fig. 9 Indexing of the lightweight aero concrete technology and comparison of different wall constructions in terms of thermal conductivity and raw density

easy due to the cement-bound material composition. The concrete matrix was explicitly designed for use without steel reinforcement to facilitate efficient recycling. The compressive strength is such that a 4–5 story building can be realized with the floor-to-ceiling panel elements. Considering the whole life cycle regarding material consumption, production, and transport, the carbon footprint is significantly improved. The figures below illustrate that the developed hybrid concrete wall provides a lower environmental impact compared to alternative wall constructions (Fig. 10).

Focusing on the abiotic depletion of fossil fuels (Fig. 11), which indicates the conservation of resources, the values for the aerated concrete mixture range between 223 and 848 MJ. The abiotic resources considered here include, for example, fossil fuels, uranium ores, mineral resources, water, air,

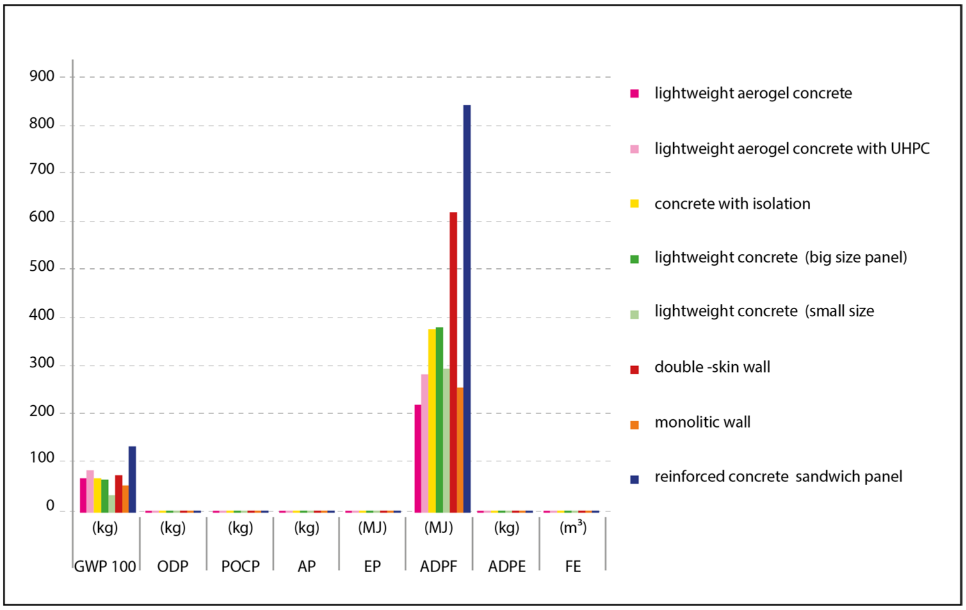


Fig. 10 Life Cycle Assessment of compared wall constructions

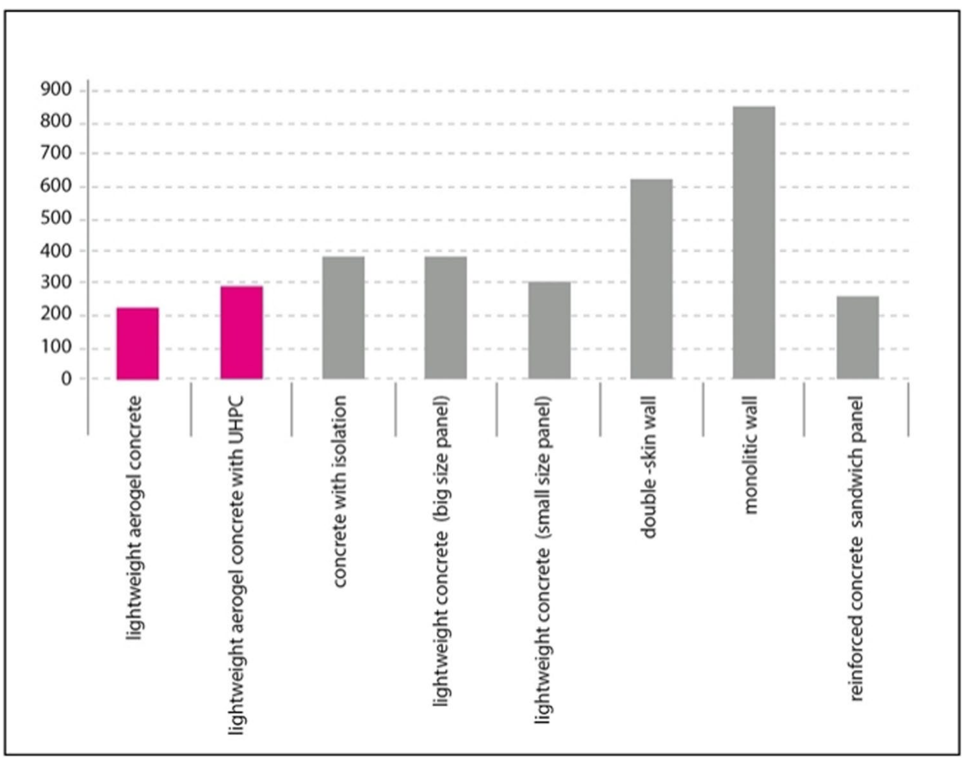


Fig. 11 Abiotic depletion potential for fossil resources—ADPF (MJ)

etc. and show the contribution to the increasing scarcity of resources. Here, too, the hybrid concrete element achieves the lowest values.

Another factor influencing sustainability is design variance. The concept allows for the development of project-specific wall dimensions, surface patterns, and reliefs or a project-related color code, ensuring architectural quality and creative implementation. One example is using formliners inserted into the previously described formwork elements to create project-specific surface finishes. (Fig. 12) As part of the holistic approach, producing such liners could or should be part of the automated manufacturing environment. Color-coding is another design feature that could be implemented using digital control systems. Currently, planners have to consider adaptive planning scenarios in their design concepts even if they exploit the benefits of integrated, automated production. Maybe such planning tasks could be further optimized in the future by employing artificial intelligence (AI).

Adaptive kit-of-parts based on reverse/mechanical fastened joining

In the design process, the principle of the hybrid concrete panel construction method was extended to a systematized open kit-of-parts, whereby the hybrid concrete wall elements were combined with prefabricated concrete components (prestressed reinforced concrete ceilings etc.). In this constellation, sustainability potentials and economic aspects can be better exploited. There are advantages in combining different prefabricated systems in a manner that each material is optimally used according to its qualities. Ultimately, a high degree of prefabrication leads to faster planning and construction processes.

Due to its homogeneous insulation effect across the entire element section, the aero lightweight concrete allows for connections that prevent thermal bridges. Therefore, the material is predestined for exterior wall applications, reducing heat transmission and simplifying the detailing. During the research, different joining principles were developed and tested on a prototypical mock-up. Figure 13 shows three different joining principles in the area of wall-to-floor and wall-to-ceiling connections. The set-up shown on the left combines lightweight area concrete wall panels with lightweight aero concrete ceiling slags. Since both building components have the same insulation properties, the ceiling slabs can be drawn to the outside edge of the wall. In the set-up shown in the center, the material matrix and the width of the notch are adjusted to prevent condensation from occurring. The set-up on the right includes a specially designed panel on the outside that features better insulation properties (Fig. 14).

A one-to-one demonstrator of assembled wall panels verified the described research. The prototype has been monitored for its long-term performance in building physics, building structure, and construction details.

Figure 15 shows the two joining principles tested on the demonstrator; one executed as a miter joint and one with a notch. Different adhesives (two-component adhesive and UHPC adhesive) were also and evaluated after long-time monitoring (Figs. 16 and 17).

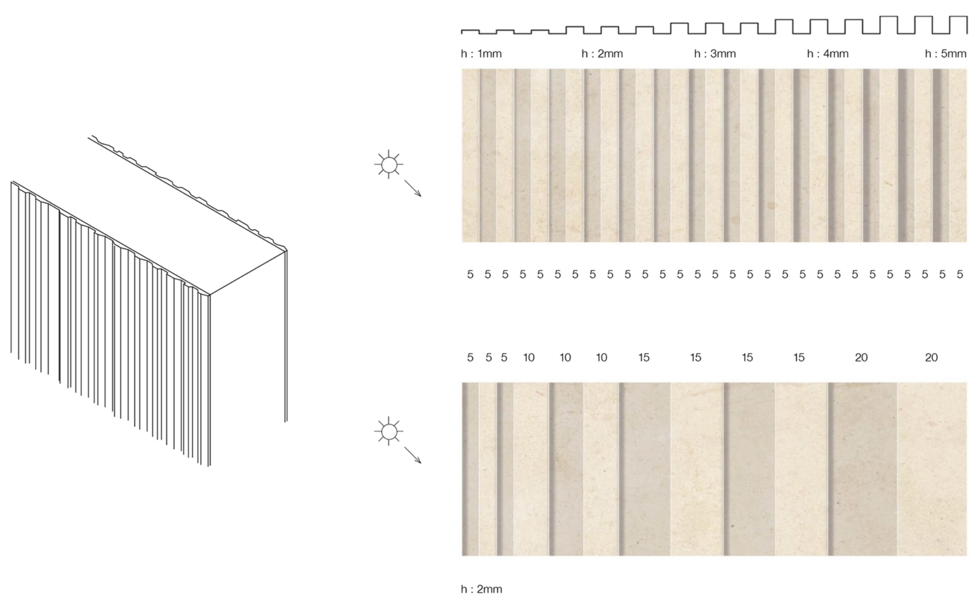


Fig. 12 Surface patterns of precast components created by inserting dies in the formwork

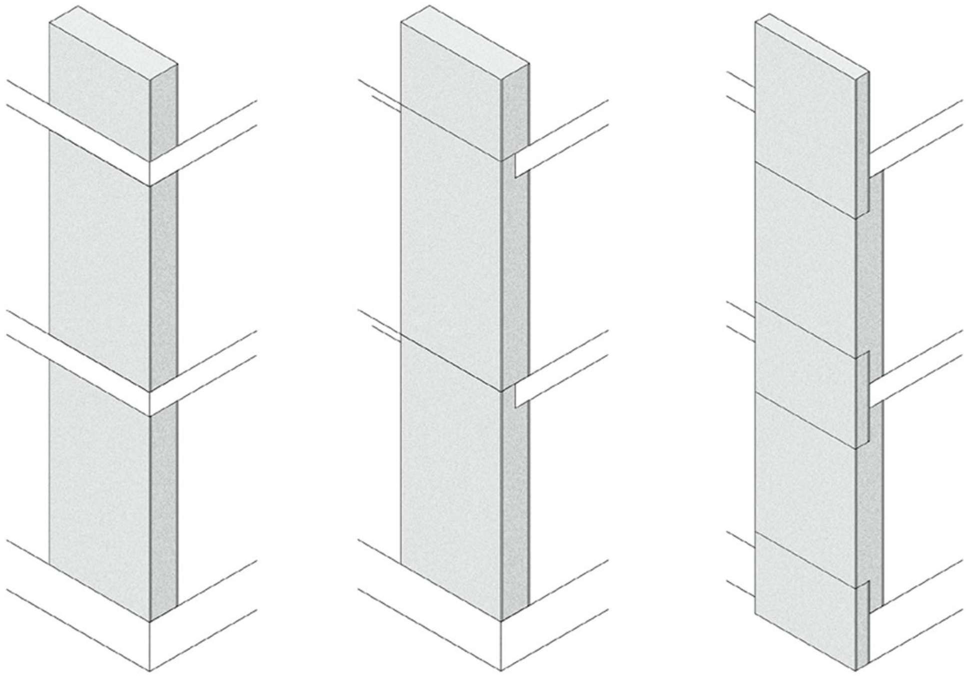


Fig. 13 Vertical connection of wall panels to provide continuous insulating properties: A) Wall panels and ceiling slabs made of lightweight aero concrete, B) Wall made of lightweight aero concrete with special connection detail to prevent condensation, C) Special panel with improved insulation properties on the outside of the joint area

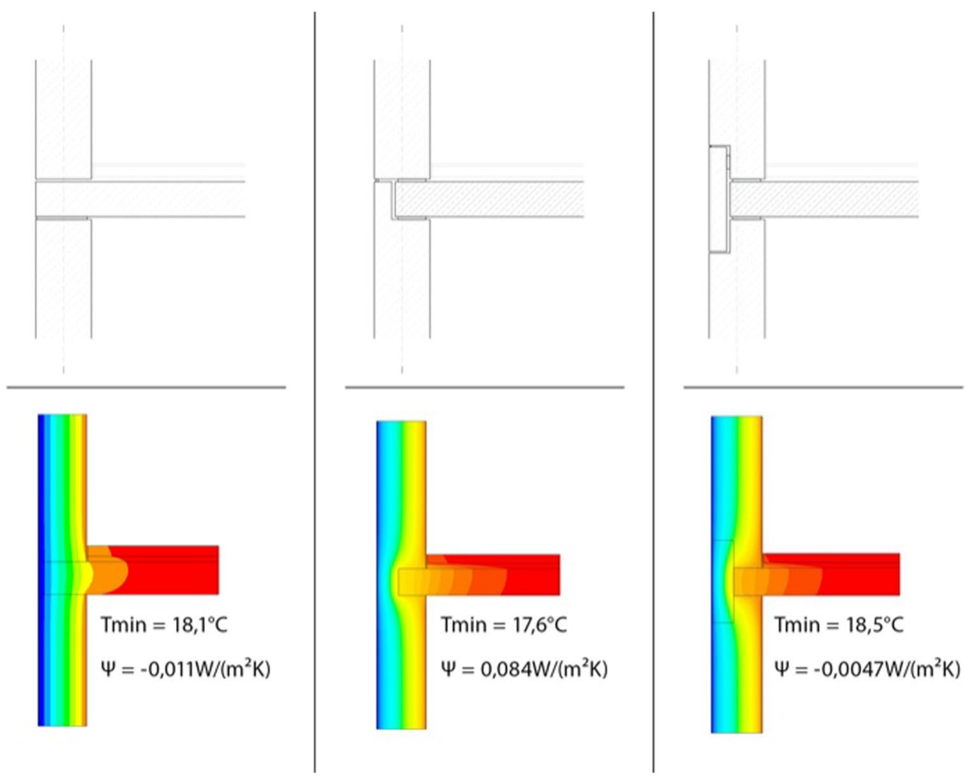


Fig. 14 Comparison of the constructive connection details incl. thermographic visualization in the wall-to-ceiling area

The mock-up and demonstrator have shown that standard joining techniques can be successfully used if a holistic design approach is employed that is based on progressive construction principles, sophisticated materials, and intelligent connections that allow for modularity rather than mere standardization (Fig. 18).

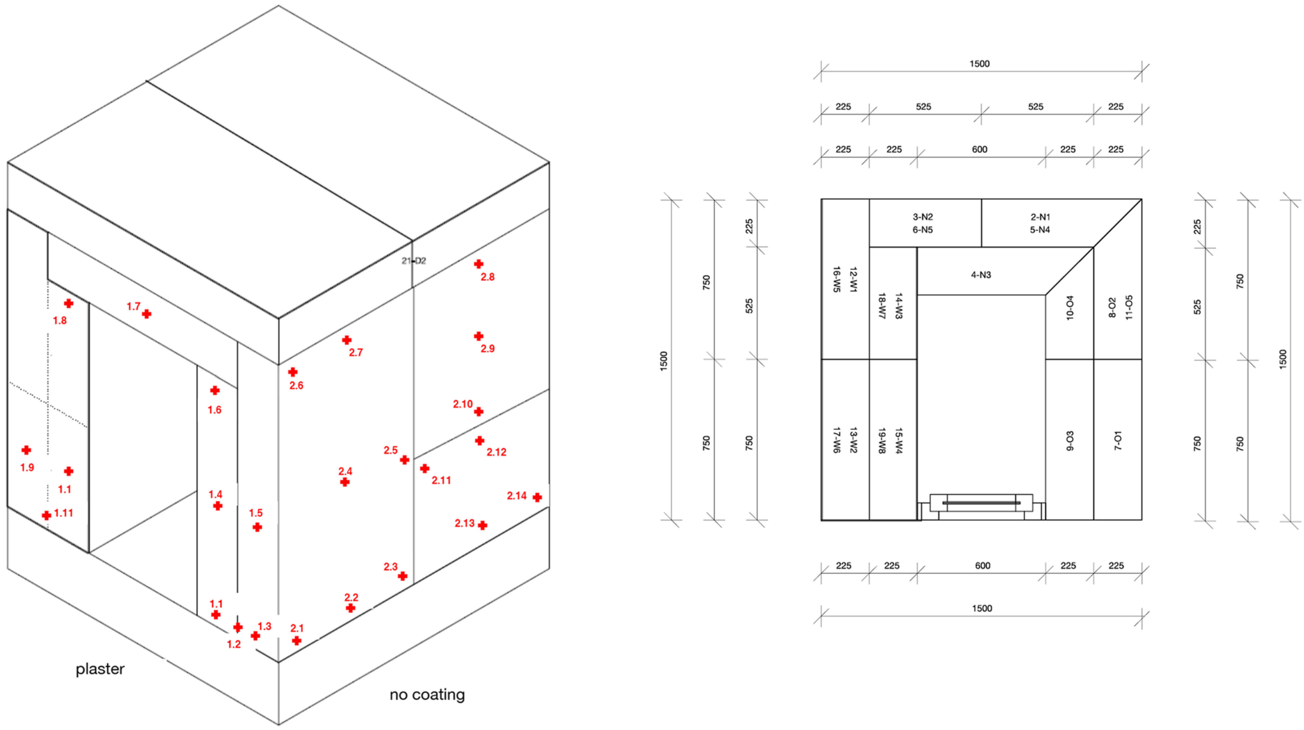


Fig. 15 Conceptualization of the different joining principles and adhesives in a one-to-one demonstrator

Ways toward a complementary manufacturing idea

Interlocking of multiple manufacturing technologies

Fully robotic manufacturing of buildings is a highly discussed topic, especially in the age of advancing digitalization. As outlined before, the predicted transformation through seamless implementation of robotics in architecture has already been exemplified in research projects. However, there is a clear discrepancy between the research projects and the systems currently applied in construction.

Fig. 16 Long-term monitoring of the demonstrator to prove the performance of the building physics, building structure and joining techniques

For the transfer from research into practice, automated technologies in general and robotics, in particular, must be critically evaluated for practical application. Even though robotic automated production machines are being used more commonly, innovative technologies often do not get beyond prototype status. A more multi-layered implementation must be pursued to apply them to large-scale construction tasks. Thus, it is not just a matter of providing a technology for the serial and (individualized) production of building components but rather about integrating the process towards an end-to-end construction workflow that maps the entire process chain, from concept planning, design and joining principles up to manufacturing and assembly.

Due to the complexity of construction tasks, it is not expedient to solve these challenges with a single overarching technology, e.g. 3D printing an entire house. It is obvious that a particular technology reaches its limits when used at different scales. Instead, dovetailing technologies can ensure maximum efficiency. The merging of multiple manufacturing technologies in a continuous production process is considered future-oriented and must be advanced. In turn, this requires a holistic view of the

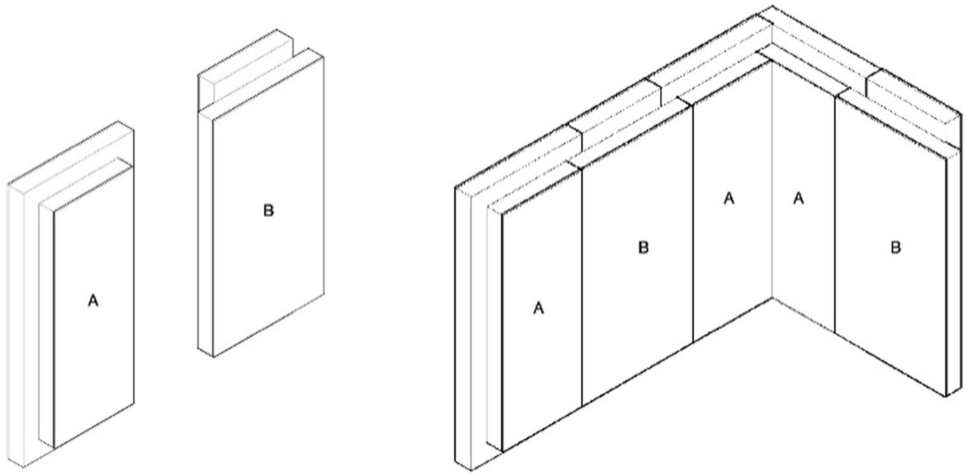


Fig. 17 Corner detail with notch joint

digitization strategy and, once again, calls for interdisciplinary collaboration in the research landscape. Robotization must be seen as an opportunity to synergize different processes and trades. In concrete construction, this would be linking the digital design tool with a robotic system, enabling the automated production of a specific material mix in order to produce a systematized but project-specific construction. This main process chain will be supplemented by interlocking technologies or machines to produce a casting or, with 3D printing, to offer a surface finish or additional reinforcement.

The approach of a hybrid precast concrete system corresponds to future needs in housing. By enabling a fast and efficient construction method, the hybrid-concrete modules lead to a systematized architecture that offers the ideal prerequisite for implementing creative and technically demanding designs.

Fig. 18 Physical prototype of the one-to-one demonstrator showing the water-repellent surface and joining quality

Outlook on an adaptive serial retrofitting strategy for the existing building stock

The applicability of the material technology to improve the insulation quality of exterior building walls offers significant advantages for its integration into the field of building renovation. In this area, very few approaches currently involve automated production methods or a higher technological standard in the work execution. Due to a large amount of individualization, renovation of the existing building stock is carried out traditionally to an even greater extent than in new construction.

Our ongoing research aims at developing a solution that leads to a serial or mass customized renovation strategy, pursuing the integration of an end-to-end digital construction process. A combination of automated production and innovative use of materials is targeted to achieve a holistic and individually tailored retrofit. Here, the lightweight aerogel technology will be further developed to be adapted to this new construction task.

For this purpose, the combination of several machine technologies explained in chapter 6.1 is envisioned to achieve a fully comprehensive approach. At first, technical-robotic processes are developed for manufacturing, followed by reprogramming serial assembly scenarios. Intelligent linking of the technical systems leads to a highly efficient application and, simultaneously, to a high-quality design appearance.

The continuous process can be described as follows: starting with a digital survey, followed by manufacturing a digitally adaptable material matrix made of lightweight concrete that acts as an insulating layer. In the end, the material matrix gets applied on the prepared surface of the existing wall using a robotic tool that works similar to a climbing formwork, layering the concrete through the nozzle head within a frame that enables easy adaption to alternating building tasks.

Current renovation systems for building envelopes apply a uniform insulation layer on the surface of the existing façade. The insulation thickness is determined by the weakest component. This results in over-dimensioning large areas of the building envelope and excessive use of materials, wasting unnecessary resources without considering the required individual qualities sensitively.

Against the background of individualized standardization, it becomes obvious that a uniform constructive-technical principle for a novel refurbishment process needs to be established. Corresponding to current technological developments in construction, it enables a certain adaptability of mineral insulation materials and, thus, responds to the individual building stock scenarios. Individually printed parts for exterior walls will be produced by integrating intelligent automation technologies. The material will be matched exactly to the specific requirements. In this way, adaptive manufacturing enables the efficient use of resources and ensures a highly efficient process.

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