OFFICE OF TECHNOLOGY ASSESSMENT AT THE GERMAN BUNDESTAG

Innovative technologies, processes and products in the construction industry

TAB-Fokus no. 36 regarding report no. 199

April 2022

Summary

- In the German construction industry, innovation activity and willingness must increase significantly in order to be able to meet the technological and socio-political goals and requirements with regard to residential construction as well as to resource conservation and climate protection.
- Obvious opportunities for increasing efficiency and productivity arise in the areas of digital planning and construction (Building Information Modeling, BIM), serial and modular construction, and data-based networking of construction processes along the value-added chain (Construction 4.0).
- In the long term, the new or further development of innovative construction technologies (e. g. 3D printing, automated machines and construction robotics) will partly also offer promising potentials.
- In view of the fact that the construction industry is dominated by small and medium-sized enterprises (SMEs), digital applications will only be successful if the needs of SMEs are consistently integrated into the innovation and standardisation processes.

What is involved

The great demand for affordable housing and the existing housing stock, which is often considered to be insufficient, represent an enormous national challenge. In order to tackle this challenge, an efficient construction industry is indispensable. In recent decades, however, the way buildings are built has remained basically the same. Masonry and concrete are still the main construction materials. Although planning now is done on the computer, the electronic planning documents are usually still treated like paper documents and exchanged separately between the various project participants. Moreover, over the past 10 to 15 years, there have also been hardly any fundamental changes with regard to the machines used on construction sites.

This is due e. g. to the special systemic framework conditions of this industry. The construction sector differs significantly from other industries insofar as it creates exceptionally durable products that have useful lives of 50 to 100 years or more. In addition, there is an almost unprecedented level of standardisation and regulation, which is primarily due to the stringent and comprehensive safety requirements for buildings. For the standardisation of incremental innovations alone (e. g. for construction materials), a time horizon of 10 to 15 years is to be expected.

There is consensus that the construction industry needs to become more innovative in order to be able – in view of the shortage of skilled workers, for example – to meet political goals, especially in the field of residential construction. Several (digital-)technological innovations are being developed – and partly also tested and applied. The spectrum ranges from the use of highly specialised construction machinery and supporting robotics during construction to innovative manufacturing processes for components (e. g. 3D printing as well as modular and serial procedures) and the generation of virtual building models (BIM).

Digital planning and construction using BIM

BIM is a software-based working and planning method. Ideally, all essential information required for the planning, construction and subsequent use of a building is processed jointly and in real time based on digital building models. One of the main differences between the BIM approach and the conventional approach is that all relevant project data and planning documents are no longer kept separately on paper and only exchanged as required – with the risk of information loss and some friction – but that all information is integrated

Client

Committee on Education, Research and Technology Assessment
+49 30 227-32861
bildungundforschung@bundestag.de

continuously into a central database. In this way, planning errors can be identified at an early stage and, in particular, costly and time-consuming retroactive planning changes can be prevented. This means that a building is first planned completely digitally and then continuously optimised on the basis of a model.

In recent years, the topic of BIM has gained significant attention in Germany as well. As a result, BIM implementation is being boosted at various levels. Nevertheless, Germany lags behind other countries in this respect. Particular challenges regarding the introduction of BIM in the German construction industry and specifically in private residential construction arise from the strong fragmentation and the high number of SMEs as well as from the strict separation of planning and execution services, which is also stipulated by procurement law.

Ultimately, the changeover to BIM should be considered less as a technical process and more as an organisational and cultural adaptation that takes time and – given the limited resources of many companies in the construction industry – should take place as gradually as possible. It is therefore important to focus support activities on SMEs today already, as they are ultimately the key to bringing BIM into widespread use in Germany. In this context, important fields of action are the development of standardised procedures for BIM practice, the establishment of sufficient capacities for knowledge transfer and consulting as well as the promotion of pilot projects.

Additive manufacturing

Additive manufacturing is the production of three-dimensional components using an automated layer structure (3D printing). Based on a digital 3D model, the requested component is tailor-made and built up successively by applying the source material layer by layer in a targeted way. Since the construction sector is characterised by one-off manufacturing, it is basically predestined for additive manufacturing processes. Although research and development increasingly focus on steel as well, 3D printing activities in the construction sector are primarily concentrated on concrete as a material. Thus, at the international level, there is a rapid increase in demonstration projects for 3D concrete printing of mostly small buildings. And in Germany as well, first pilot projects are being implemented.

Printed house made by the Chinese company Greenprint

Source: Viktor Mechtcherine

In practice, extrusion processes are the most common. In these processes, fresh concrete is continuously deposited layer by layer through a nozzle or print head. As a matter of principle, this allows for a wide range of architectural design options and rapid construction of buildings. However, there are still some technological challenges to overcome: Thus, e. g. the conflicting demands on the material to be printed in terms of good pumpability, continuous and rapid material deposition, and immediate deformation stability even under load prove difficult to meet. Another key issue is the lack of practice-oriented solutions for direct integration of reinforcement into additive manufacturing. Moreover, ceilings currently still have to be installed conventionally.

Overall, intensive research and development activities are still needed to make additive concrete printing processes applicable in the construction industry. Another major obstacle is that neither the construction materials used (3D concretes) nor the additive processes themselves comply with the existing construction standards. As a result, currently only approvals for individual cases are possible – which is time-consuming and expensive. Here, further development of standardisation is required taking into account the special features of the new construction method.

Serial and modular construction

In serial and modular construction, buildings are not planned and constructed as one-offs. They are either serial products from industrial manufacturing processes or assembled from industrially prefabricated components (modules) following the modular principle. Serial and modular construction methods are now increasingly discussed when dealing with the future of construction, i. a. because digital and largely fully automated prefabrication methods enable unprecedented complexity, variability and precision of prefabricated components and modules.

Consistently adhering to the principle of series throughout the entire process can save costs and allow construction projects to be completed much faster while maintaining high precision. Another advantage of a high degree of prefabrication is that interruptions in production due to weather conditions can be avoided. As a matter of principle, 24-hour production in shift operation is possible. Due to these factors, companies specialising in modular construction are able to provide a higher degree of transparency with regard to planning and scheduling. Unlike in Great Britain or the Netherlands, however, modern modular and prefabricated construction has not yet been widely established in German residential construction and is still mainly limited to single-family houses based on timber construction.

Modules and prefabricated components are usually made of reinforced concrete, wood or steel or a combination of these materials, each having its own specific properties and thus advantages and disadvantages. A crucial question is how multi-storey timber construction – which is particularly advantageous from an ecological point of view – can gain in importance. Building with timber can bind large quantities of CO_2 in the long term and substitute energy-intensive construction materials such as brick, cement and steel. However, the lack of e. g. manufacturer-independent standards is proving to be an obstacle. These standards would be important to ensure compatibility, expansion and reuse of the modules. In order to accelerate and simplify the construction of type houses from series production, it is necessary first and foremost – in addition to wide-ranging research activities in the fields of building construction, statics and materials technology – to develop standardised solutions as well as a type approval that is regulated as uniformly as possible throughout Germany.

Construction 4.0 – overarching aspects

The aim of Construction 4.0 is to seamlessly network the individual digital solutions along the planning and construction value-added chain in order to enable more flexible, data-based control of construction processes and thus tap the efficiency potential involved. Altogether, the degree of digital networking in the construction industry is still low. And it is precise-

Perspectives in the field of automated construction machinery

Due to its key role in construction processes, construction machinery has a decisive influence on the effectiveness and efficiency of construction work. This is why automated construction machinery offers a considerable potential for increasing productivity on the construction site. Automation is particularly useful when work steps that can be well planned are repeated according to clear patterns or when they are executed continuously over a longer period of time – such as for road construction. In contrast, the general framework conditions on building construction sites are usually much more confusing. Despite numerous ideas and approaches, the real implementation of automation functions is still a long way off.

For the foreseeable future, innovative machine concepts – such as autonomous construction machinery or construction robots – will most likely be limited to those specialised tasks where the presence of humans in the machine's work area can be largely dispensed with (such as 3D concrete printing machines or demolition robots). The general trend, however, is more towards increasing partial automation of individual work steps. The current state of the art already includes numerous manufacturer-specific as well as manufacturer-independent assistance systems (some of which are offered by third-party suppliers).These systems – usually in combination with suitable sensor technology (e. g. for determining the relative position of the work equipment) – serve to protect people, relieve the burden on operators, improve process accuracy, and manage machines and fleets. Accordingly, the current focus of research and development is on the evaluation of sensors suitable for the construction process (environment recognition, condition detection of soil and construction materials, etc.) and the development of algorithms for reliable object and process classification as well as for machine control.

ly the interfaces between the already existing tools of digital construction planning (BIM, etc.) and the tools of digital, automated production (additive manufacturing, modular/serial procedures, construction machinery, etc.) that are still underdeveloped. Above all, there is the question of what digitisation can contribute to making the extraordinarily energy- and resource-intensive construction sector more sustainable. For this purpose, in addition to the implementation of digitisation and automation technologies, the development of sustainable, low-CO_2 construction and building materials technologies that meet the requirements of a sustainable circular economy must be driven forward. Particularly with regard to low-CO_2 or CO_2-neutral cements, the construction industry is facing major challenges.

In view of the enormous, wide-ranging research needs, it would make sense – in addition to increasing funding – to develop an interministerial research strategy in order to deploy resources in the most targeted way possible and to exploit synergies. What is needed in particular are long-term programs that enable follow-up projects. It often proves to be a problem that funding usually ends well before a product is ready for the market, and the different approaches developed are not followed up after a project has been completed. Particular attention should be paid to ensuring that not only larger corporations, but also SMEs participate in publicly funded research and development projects.

The digital networking of the construction industry along the value-added chain is currently also failing because the infrastructural prerequisites are inadequate. Thus, there is e. g. a lack of manufacturer-independent data portals via which the machine and process data generated on the construction site can be exchanged between the parties involved. Here, many machine manufacturers pursue proprietary solutions, which is not appropriate for the rather heterogeneous machinery of many construction companies. Moreover, the communication networks that can be used as standard today are hardly suitable for meeting the demanding communication requirements of remote-controlled construction machinery or cloud-based process control systems. Finally, the digitisation of procedures regarding planning law and building inspection is important for accelerating residential construction. During the ongoing digitisation efforts of the building authorities, care should be taken right from the beginning to ensure that the procedures are consistently aligned to be BIM-compatible, as this is a key prerequisite for the creation of an end-to-end digital process chain.

Without a doubt, the digital transformation will take some time, and driving forward technology development alone will not be sufficient to ensure that innovations will ultimately be put into practice. With regard to the ability to implement innovations in the construction industry, a much broader perspective is required instead, which also includes environmental aspects, systemic framework conditions as well as soft cultural aspects (operational management, willingness to take risks, culture of communication, etc.). In view of the fact that the construction industry is dominated by SMEs, digital applications will only be successful if they meet the requirements and needs of SMEs. This is why SMEs should have the opportunity to participate in the innovation and standardisation processes. For this purpose, appropriate structures must be created or expanded (e. g. regional competence and demonstration centers, information and consulting services, low-threshold support measures). When it comes to transferring target-oriented and sustainable innovations into practice, the state in particular has a significant role to play as a major building owner.

TAB report no. 199

Innovative Technologien, Prozesse und Produkte in der Bauwirtschaft

Christoph Kehl, Matthias Achternbosch, Christoph Revermann

Website of the project
www.tab-beim-bundestag.de/en/hightech-bau

Project manager and contact
Dr. Christoph Kehl
+49 30 28491-106
kehl@tab-beim-bundestag.de