NO AM PERSPECTIVES FOR THE BUILDING INDUSTRY: AN ESSAYISTIC VIEW

Holger Strauß

From the 1990s to the 2010s, rapid prototyping, 3D printing and additive manufacturing were hyped technologies with great expectations. There was great hope that they would also trigger a surge of change in construction technology and in the specialist discipline of façade technology. This was linked to the hope that they would lead to fundamentally new ways of thinking and production methods in architecture and construction technology.

These expectations were not met in full. Based on the examples that have actually been “printed” to date and against the background of current social developments, the author not only sees a delay in development, but also predicts the premature end of the further development of additive processes for construction technology. Only a few niche products will remain from the large number of available AM technologies in construction technology that can be integrated into established production processes. This will not result in a new building typology or a 3D-printed building envelope.

There is no perspective for AM in construction technology – a provocative assertion in an essayistic (retrospective) view.

BACKGROUND AND EXPECTATIONS FOR 3D PRINTING IN CONSTRUCTION TECHNOLOGY

The development of additive processes (hereinafter referred to as “Additive Manufacturing – AM”) has been very dynamic since its inception in the late 1980s, with regular further development, both in the technical variants of the system technology and in the variety of materials that can be used. The principles of AM technologies and their development can be found in the literature. [1-3]

Various traditional materials are currently available for use in construction technology that enable the additive production of building components for the building envelope: steel and aluminum, clay and concrete, approaches in glass, as well as AM-specific plastics, some of which are comparable in their properties to the plastics used in construction technology.

After deciding on the technical objective of an AM component, the right material can be selected and the right AM system technology can be found via the material.

Nevertheless, AM is still not a relevant technology in the construction industry, and even less so in the specialized discipline of the building envelope.

WHAT WERE THE TECHNICAL REQUIREMENTS FOR AN AM BUILDING ENVELOPE IN 2010, AND WHY IS THERE STILL NO ANSWER IN 2025?

In order to develop and justify an AM building envelope in all its consequences, the performative properties of this new AM building envelope must achieve significant improvements compared to conventional façade technology. Ideally, the requirements for a dynamic building envelope can be met: Climate regulation through breathable materials, load transfer through slender-optimized supporting structures, comfort through active insulation and ventilation, integrated technology for the user, performance for lighting and shading with adaptive transparency, a design-appropriate appearance.

In this context, it is important not to pursue the dynamic building envelope as a technological end in itself, but to see it as an opportunity to take the development of the building envelope to the next level, which has been stagnating for years. Mike Davies' "Polyvalent Wall" is still unrivaled as a product in its complexity and yet slender design, but unites all desires for the building envelope in a concrete formulation. [4]

Further approaches were derived from the development of façade technology and specific requirements for the building envelope were established. The need to further develop the façade in order to respond to new demands on the building envelope is undisputed. [5]

But why are specific ideas not being applied?

One reason for the hesitant acceptance of new approaches in the construction industry is a conservative attitude. The individual trades in construction activities remain strictly separated from one another, even if combining different disciplines would bring advantages for the overall product. This is partly due to the legal separation of individual construction services, which is becoming increasingly important, and partly due to a widening knowledge gap in the area of skilled workers and the associated lack of intellectual freedom to evaluate and try out new things.

WHICH FURTHER DEVELOPMENTS IN AM TECHNOLOGIES FOR THE BUILDING ENVELOPE PREDICTED IN 2010 WERE REALIZED?

Looking back, the author summarizes the requirements for the further development of AM technologies for the development of market relevance in 2010. The following conclusion can be drawn about the development since the invention of the first Rapid Prototyping systems in the 1980s until today.

For the period from 2010 to around 2015, AM technology should have changed the content of existing construction details. Nevertheless, even today, in 2025, AM is still not a decisive technology for the creation of outstanding architectural projects. This means that either development has been significantly slower over the past 15 years, or AM is an overrated technology in terms of construction technology.

Excursus: In the same period from 2010 to 2025, the proportion of digital processes in the construction process has increased significantly. The late project phases, e.g. the planning and implementation of the building envelope, have already matured as a flowing digital process up to production planning and component production at the major metal fabricators. A genuine file-to-factory process that would easily enable the integration of AM technologies - yet this integration is not taking place.

In the period from 2015 to around 2025, AM could also have found its way into the workshops of façade builders due to further improvements of AM systems. Nevertheless, it should be noted that conventional manufacturing principles continue to predominate in facade construction. Although there is increasing digitalization in production, there is no shift towards new technologies. Sheet metal and profiles are still processed conventionally, albeit at a higher technological level. Examples include fully automated bending benches, sheet metal punching machines and CNC processing centres, which are now fully digitalized, from material supply and processing optimization with automatic tool changes to coding and marking for transport and logistics.

Excursus: Since the 2020s, there have been product approaches from various suppliers to manufacture complex façade components using the Nematox II façade node principle with AM production. However, it should be noted that the production of complex façade nodes as CNC milled parts still offers advantages in terms of costs and production times. Although the "gap" between CNC production and AM production is narrowing every year, this shows that the advantages are not to be found in the technology alone.

For the period from 2035 to around 2040, the system houses should have been able to produce hybrid façade components using AM processes at the originally assumed development speed. In other words, complex, dynamic building envelopes with a wide variety of materials, in combinable processes, for the production of complete components including the associated primary structures. However, it should be noted that even on a laboratory scale - in 2025 - no hybrid components are currently being tested. The various material approaches generally relate to monomaterials and are still at the basic research stage. Therefore, taking into account the development cycles for new technologies of 15-30 years, such an evolutionary leap is no longer possible by 2035 from today's perspective.

Figure 1: from left to right: challenging geometry, problem detail (unsolved), prototype of the AM solution "Nematox II" AM-Façade node (H. Strauß, 2010).

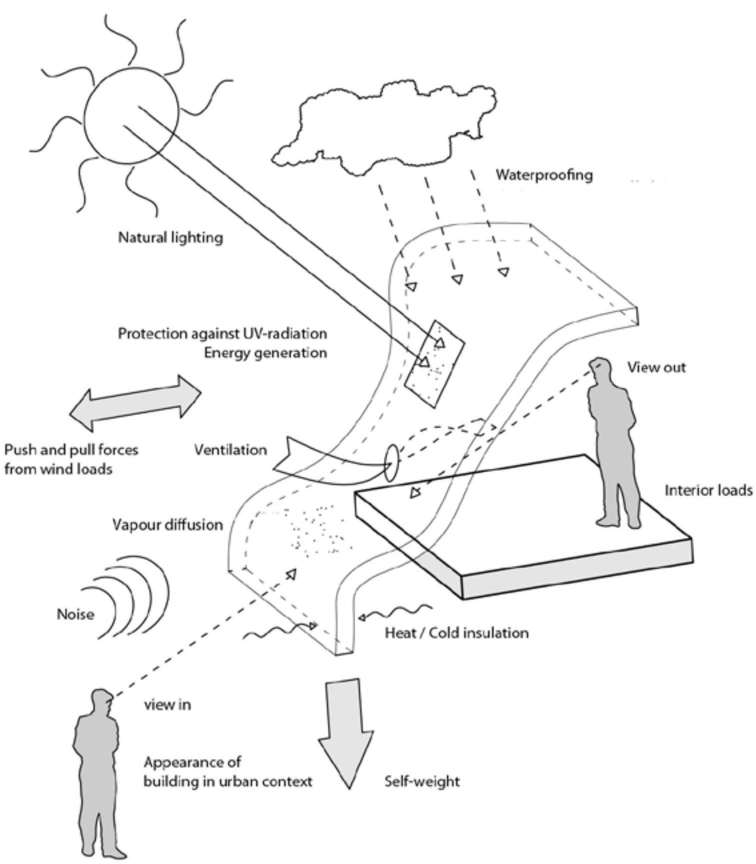

Figure 2: Facade Performance by Knaack et al. [4] – traditional approach, 2007.

Excursus: Approval concepts are required for dynamic building envelopes and their components, which are not currently available. Current efforts do not even begin to show the multi-material solutions that would be required.

In current approval procedures in construction technology, it can be observed that even combinations of already known materials and construction components are difficult to implement. It is therefore very difficult to establish and disseminate innovative, improved building products. The necessary change in renewable energies and their integration into the building envelope is cited as an example. Here, for example, frameless all-glass PV-modules need to be approved for general building applications. The known components here are laminated glass and structurally bonded backrail systems. The administrative act on the way to an approved innovation manifests itself in a paralyzing slowness.

This prevents new developments involving completely unknown processes and products and makes market innovations almost impossible. Added to this are high investment costs and the resulting high entrepreneurial risk involved in carrying out approval procedures. The return to traditional principles is therefore understandable.

INTERIM CONCLUSION

Thus, even 40 years after the initial spark of AM by Chuck Hull, 35 years after the first concept of "contour crafting" for printing entire buildings by Prof. B. Khosnevis [6], 20 years after the first ideas for application in façade technology [1, 7] and 15 years after the development of the first façade node for the integration of AM technologies into a standard mullion-transom system by the author [8, 9], AM technology has not managed to revolutionize production methods. It remains a niche solution with no impact on the construction industry.

The basic requirements for the application of AM in the construction industry and in façade technology are still in place and date back to the early days of AM research:

- Transfer of Rapid Prototyping technology into an AM production technology
- Margin-independent production of exactly the same components
- Adaptation of system sizes to the requirements of construction technology
- Reduction of production times
- Reduction of production costs
- General building authority approval of AM technologies and AM materials

The author's thesis from 2013 that "additive manufacturing (AM) is changing the way we design, construct and produce building envelopes" could not be confirmed.

THE EMERGENCE OF NEW INFLUENCING FACTORS

However, it is clear that today completely different topics have replaced the original technology hype in favor of more important social issues. During the ongoing discussion about 3D printing in construction technology, the technologies have found their way into our everyday lives, but not into our built environment.

Factors influencing development today are the proven climate change [10], global economic developments since the Covid pandemic, economic changes and rising energy prices, the Russian war of aggression in Ukraine, the crisis in the Middle East, etc.

The accompanying changes in society's focus - away from specific innovations in less relevant niche markets and towards issues affecting society as a whole - is a natural development. What is really important, what are we focusing on?

In the construction industry in particular, completely different topics have emerged over the past ten years, which have a much greater impact on what we build and how we build in the future.

WE MUST CHANGE FROM A LINEAR ECONOMY TO A CIRCULAR ECONOMY!

The building sector is currently facing this changed situation. The market area of conversion, renovation and construction in existing buildings is becoming increasingly important. The demand for flexibly usable properties and new concepts for the permanent use and flexible occupancy of buildings is growing.

In recent years, the demands on the building envelope have shifted from purely technical and aesthetic aspects to complex requirements regarding the afore mentioned material properties and more extensive requirements for operation and sustainable management.

A façade must fulfil various requirements, mainly technical and/or design issues. Still continuing in every project until today – the well-known façade basics (see Figure 2).

But the demands on our built environment are currently changing at an unprecedented speed - new challenges from the above-mentioned subjects are leading to a new situation to which the involved disciplines must react. Today, a façade must fulfil various new requirements and must offer other façade functions. New challenges that must be addressed together with owners, manufacturers, as well as planners and research institutions with well thought-out and innovative approaches.

To be able to deliver the needed high complex and highly specific building envelope solutions, we need to foster our knowhow and the way of how we plan and execute facades with the stated claim. To do so, we need to rise our expertise and specialist knowledge, we need to rise the applied planning parameters, we need to become more aware of trades interfaces and how to cope with them for a better building result, we need to tackle and solve existing software interfaces that hinder a free information flow in the current projects, we need to face global/environmental demands and come up with technical solutions like the usage of circular aluminium or sustainable glass products or so called green steel, and we need to raise the awareness about the need for certification, to be able to track and document the efforts that we undertake to enhance building technology. But AM is not an essential part of this discussion!

RECURRING DEVELOPMENTAL WAVES AS AN EXPLANATION FOR FAILURE?

In the context of recurring development waves in the discovery, development and establishment of new technologies, for example in Gartner's Hype Cycle [11], promising approaches are sometimes "overrun" by other evolutionary waves over the course of their own development and lose relevance on the way to becoming established technology. But contrary to the thesis put forward by Prof. Dr.-Ing. Ulrich Knaack that we were right before the actual peak of evolution in 2015 ([2], pages 117ff), don't we have to admit today - in 2025 - that the peak has not materialized?

Where is there a technology transfer from research to application? Where did AM prototypes become AM system components? Where could the digitized, parameterized design activity be transferred into a construction method, into a construction language through AM?

The few designs that make the use of AM absolutely necessary are still an expression of digitally driven design activity. The few projects or sub-projects are usually niches within a niche in relation to a regular building construction project. This means that AM solutions for the application of technology in architecture also remain in this niche.

We can only hope that we are still in the "disappointing" phase (see Figure 3) and that the establishment of AM technologies is only delayed.

What remains after a current examination of the market is a single approach in the realization of 3D-printed structures on a 1:1 scale, with which a small market access has been achieved:

3D-PRINTED HOUSES

There have been commercial developments in the field of concrete printing for around 10 years, resulting in "3D-printed houses". Another thesis put forward by the author in 2013 was thus partially refuted, which from today's perspective could be seen as a partial success of additive processes in the field of 3D printing of concrete structures. The thesis was that in future "[...] no entire buildings will be printed [...]".

The first printed town houses were presented in China in 2014.[12] There was no claim or intention for technology-appropriate planning or material-appropriate construction, which meant that the first examples remained at the very bottom of any conceivable development.

The related examples from the recent past show focused approaches to large-scale construction technology. Interestingly, all examples here also initially remain within the framework of classic single-family houses - from the 3D printer. [13]

All efforts to incorporate AM components into conventional construction operations are doomed to failure, as the perspective from which they are conceived is that of yesterday. Thus, at the end of the novel manufacturing process - the actual printing - standard components are used to make the supposedly new usable in the context of regular use:

- Doors are mounted in irregular concrete reveals and "made to fit" with construction foam.
- The necessary emergency overflows and spouts are not integrated during the construction of the parapet, but are drilled afterwards.
- The parapet detail is designed without a new approach, as in a conventional building, but cannot be executed with a sheet metal flashing, as the geometry is "free-form" - so liquid plastic waterproofing is then used.
- Necessary construction joints are executed, but are not thought of in the context of the AM process - and subsequently filled with a sealant. However, this cannot be smoothed properly as the wall surface is an AM surface.

This simple commentary on "3D-printed houses" shows only a small part of the necessary changes that currently still stand in the way of AM-appropriate construction. The reality of the construction site is catching up with the digital possibilities of virtual planning, as is the tension between construction performance and the recognized state of the art. What compromises does a client have to make when ordering a printed house? What new aspects of performance can they expect? These questions are also largely unresolved in terms of normative and legal regulations.

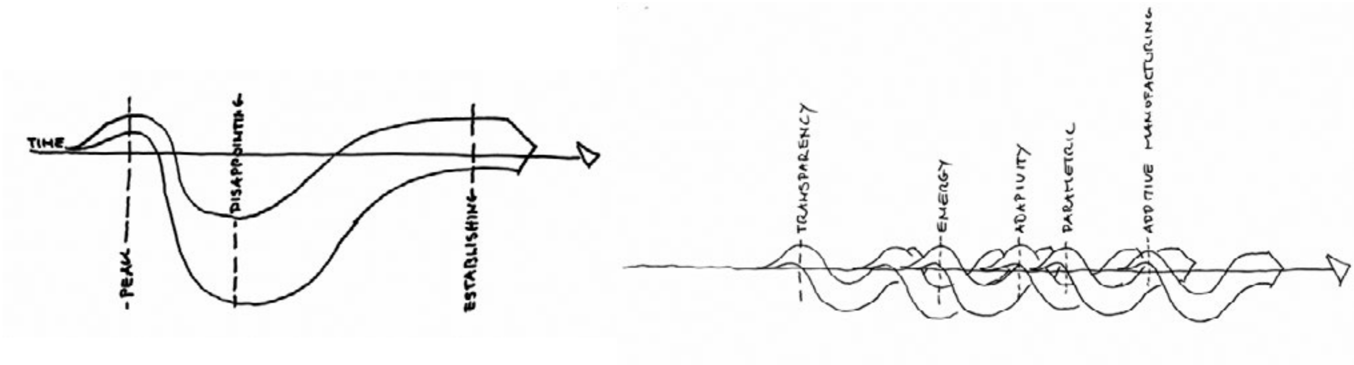

Figure 3: Development Waves, U. Knaack.

Figure 4: Images of a 3D-printed building in Heidelberg, Germany. From left to right: spout in construction foam, expansion joint in 3D printed wall, parapet finish with liquid plastic sealant.

The project shown in Fig. 4 is an early generation of development. In the current generation of the 3D-print ed house, some of the above-mentioned problems have already been solved. Here too, the learning curve is steep and development follows a development wave.

The objective is not freeform, not the daring architectural design or pure fascination with the technology. When AM is used in this context, the specific aim is to find the required niche in the market and to exploit economic advantages. A very specific project size, time savings and speed of construction, as well as the trade-off between the cost of the plant technology and labor costs must give AM methods an advantage over conventional construction. [14]

After looking at the initial results, the expert reader must realize that the underlying idea for AM as a series solution in construction technology has initially failed!

What remains is the realization that AM is and will remain a technical solution for prototype construction. Outstanding architectures are always prototypes. Unique by definition, and their implementation must be seen in the same way: Prototyping and not series production. Where the system solution ends, AM remains a means of choice and has its justification precisely for this, just like traditional craft techniques or individual CNC solutions for the production of individual parts.

What needs to happen to make this failure a success after all?

CALL FOR REVOLUTION

If AM is to develop into an independent production method in the construction industry after all, then a completely self-sufficient and revolutionary, independent genre for architecture must also develop. Such an independent application would therefore no longer be limited per se to "the façade", "the primary structure" or "the room enclosure", but would plan a building as a whole. In its full consequence, the decisive part of the production method used should be limited to additive processes so as not to dilute the strong potential of "AM Architecture" with aids from conventional production. This could give rise to a type of building similar to those produced by traditional construction methods, such as half-timbered houses, brick buildings, etc. This is an extreme demand, but from the author's point of view it is the only way to finally realize the potential of AM, if it is needed at all for our built environment.

WHAT ARE THE CURRENT ARGUMENTS AGAINST THE SERIAL USE OF AM?

Developments in recent years show that there are decisive challenges and hurdles that speak against the serial application of AM in the construction industry and in façade technology.

1. High initial investment, high specialization of the individual AM system
   The integration of an AM for façade production requires high investments in specialized systems and materials. In particular, large-format printers, which are required for the construction of large-format structures, will only be available to a limited extent in 2025. The fact that each AM system only covers one material group and each AM system requires very specialized software significantly limits its use in series production.

2. Material restrictions
   Currently, there is only a limited range of materials approved for AM in construction. Concrete, plastics and specially developed mixtures are commonly used materials, but they have their own limitations in terms of strength (anisotropies), durability (long-term experience, test procedures) and environmental friendliness (recyclability). There are not yet sufficient material characteristics and verification procedures to enable the uncomplicated use of individual materials in construction technology. In most cases, unregulated products are used for which a project-related approval procedure has to be carried out. This contradicts an application in an approved building product or façade system.

3. Slow print speed
   Despite the potential efficiency of AM technologies, the process in the construction industry is still comparatively slow. The construction of large numbers of individual components in metal can take anywhere from several hours to several days per construction job. If you think of a façade structure consisting of a mullion and transom façade, several hundred façade nodes are required for a more complex geometry, depending on the façade surface. Cost and effect are not yet in a balanced relationship here. Today, system components can be milled faster and more reliably on CNC systems, for example.

4. Lack of regulatory clarity
   Compared to traditional construction methods, there is a lack of clear norms and standards for AM in the construction industry. This not only makes quality

assurance more difficult, but also acceptance in the construction industry and safety for use in series production. Without uniform guidelines, uncertainties can arise when using AM components.

5. Technological immaturity
AM technology is not yet fully developed. Many of the existing AM systems are still in an experimental phase. Even though AM has already achieved success in smaller areas, the equipment and processes for larger and more complex construction projects have not yet been developed.

CONCLUSION

AM has evolved from Rapid Prototyping in the 1980s to a versatile technology that is now used in numerous industries - from medicine and consumer goods to aerospace. Nevertheless, most applications remain in the prototyping phase, either due to a lack of requirements for product repeatability (consumer goods) or due to the application with the expectation of an individual prototype (medicine, aerospace).

Installation space and material availability are further limitations that prevent the simple scaling of existing AM processes to construction technology.

The most successful AM product in the construction industry at the moment is probably the 3D-printed house, which, however, falls far short of the originally expected revolution in the construction industry in terms of its design and construction. The 3D-printed house has developed as a niche product in the construction industry. There are repeated attempts to utilize the advantages of the technology for the construction of emergency shelters or housing for socially disadvantaged people. It can provide a sustainable, cost-effective and fast solution for the construction of housing. However, this application has a different objective for the use of the technology than the initial vision of AM as a solution for complex building envelopes.

In today's construction activity, it can be seen that large-scale projects are increasingly driven by investors' profit motives. Projects are already traded on the real estate market during the development phase. The connection to the project is usually not the result of the owner's vision, but is driven by the market. Over-regulation and tough planning processes with an excessive bureaucracy and a growing planning team increasingly lead to a significant delay in the committed schedules and exploding construction costs. The implementation of construction planning on the construction site is currently characterized by raw material bottlenecks, a shortage of skilled workers and price wars. It is clear that we are finding it difficult to realize projects even with established construction technology – so what is the attraction of making things even more complicated?

In the current situation, the focus is on the existing building stock, the conversion of existing buildings for new uses and the increasing demand for affordable housing. The development of high-tech solutions for realising a small number of freeform, one-off architecture does not meet the demand. Funds for the development and promotion of such technologies can be used more sensibly for future-oriented approaches, such as the promotion of biodiversity, the integration of circular constructions and materials, etc.

The author's appeal at this point is to urgently reduce overregulation and to promote and demand low-tech solutions. Simple components with basic materials that can be joined by hand and also separated by type. Fewer toxic hybrids, more low-tech.

In addition to, and not in contrast to, the low-tech approach, digitalization is a major driver of change. It has been strongly promoted in recent years, but is still lagging behind in Germany in an international comparison. The use of its advantages can lead to a significant increase in efficiency, a reduction in costs and a higher quality of construction projects. This makes it a key technology for the future development of the construction industry. It makes it possible to streamline the planning process, which currently accounts for a large proportion of construction costs, and is therefore a much more likely approach to change than the introduction of a new (production) technology.

The solution therefore lies much more in the improvement of planning processes and in construction activity oriented towards common goals. A sense of purpose in standardization and regulation, courage in the implementation of alternative approaches - in the interests of the environment and future generations.

A challenge to change.

REFERENCES

[1] Ulrich Knaack, Marcel Bilow, and H. Strauß, *Rapids - Layered Fabrication Technologies for Facades and Building Construction*. imagine 04, ed. U. Knaack, T. Klein, and M. Bilow. Vol. 04. 2010, Rotterdam: 010 Publishers. 128.

[2] Knaack, U., et al., Rapids 2.0. imagine 10, ed. U. Knaack, T. Klein, and M. Bilow. Vol. 10. 2016, Rotterdam: nai010 Publishers. 128.

[3] Wilfinger, M., et al., *Ziegel aus dem 3D-Drucker*, in *Mauerwerk-Kalender, Kunststoffverankerungen Digitalisierung im Mauerwerksbau*, D. Schermer and E. Brehm, Editors. 2021, Wilhelm Ernts & Sohn GmbH & Co. KG: Wilhelm Ernts & Sohn GmbH & Co. KG. p. 435.

[4] Knaack, U., et al., *Facades.* Principles of Construction. 2007, Basel: Birkhäuser Verlag AG.

[5] Klein, T., I*ntegral Façade Construction - Towards a new product architecture for curtain walls.* Architecture and the Built Environment, ed. A+BE. 2013: abe.tudelft.de.

[6] Khoshnevis, D.B. *Contour Crafting Corporation*. 2025; Available from: http://www.contourcrafting.com.

[7] Strauß, H., *Funktionales Konstruieren - Einfluss additiver Verfahren auf Baukonstruktion und Architektur*, in *Fachbereich 1 - Lehrgebiet Konstruieren und Entwerfen*. 2008, Hochschule OWL: Detmold. p. 136.

[8] Strauß, H., *AM Facades - Influence of additive processes on the development of facade constructions*. 2010, Hochschule OWL - University of Applied Sciences: Detmold. p. 83.

[9] Strauß, H., *AM Envelope - The potential of Additive Manufacturing for facade construction*. Architecture and the Built Environment, ed. A+BE. 2013: abe.tudelft.de.

[10] Nations, U., *Kunming-Montreal Global biodiversity framework - Draft decision submitted by the President* U.e. programme, Editor. 2022, UN environment programme: online.

[11] Gartner-Inc. *www.gartner.com.* 2025 [cited 2025 09.03.2025]; Available from: https://www.gartner.com/en/articles/what-s-new-in-the-2023-gartner-hype-cycle-for-emerging-technologies.

[12] Dambeck, H. *3D-Drucker fertigt zehn Häuser an einem Tag* Spiegel Wissenschaft 2014 [cited 2025 07.03.2025]; Available from: https://www.spiegel.de/wissenschaft/technik/china-haus-mit-3-d-drucker-hergestellt-a-963249.html.

[13] Daniel Weger, et al., i.*tech 3D Sonderdruck aus beton*, in beton. 2021, Holger Kotzan: concrete content UG (hb).

[14] Korte, W., Gespräch: "*Größtes 3D-Druck-Gebäude in Europa*", H. Strauß, Editor. 2025.

ILLUSTRATION CREDITS

Images in figure 1 and 4 by courtesy of the author. Illustrations in figures 2 and 3 by courtesy of Ulrich Knaack.