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# AM Envelope - Potentials of Additive Manufacturing for facade construction

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**Abstract:**
Not only in the medical, aviation and automotive industry, the Additive Manufacturing (AM) processes are being looked upon as increasingly important production processes.
But also the construction industry is realizing more and more the chances and opportunities, that open up with these technologies for different designs and new details.

The investigation on the changes and impact of these new technologies to the design process and to the application in architecture and facade construction is focus of the research activities conducted by Dipl.-Ing. Holger Strauss.
The first extensive research project on this issue - "Influence of Additives Processes on the development of facade constructions" - was established 2008 in cooperation with the internationally operating company Kawneer-Alcoa in the research focus "ConstructionLab" at the Detmold School of Architecture and Interior Design. Focus of the project is initially on the efforts of evaluating possibilities for the production of facade components with AM processes to complement the standard products in system facades. The use of AM and high-tech CAD-CAM applications require a new kind of design. Not to design for production anymore, but to design for function - "Funktionales Konstruieren".

The paper gives a brief overview of visions and applications of Additive Manufacturing in the field of architecture and facade construction. It shows ideas and results from conducted research projects and teachings at both, the Technical University of Delft, Netherlands, and at the University of Applied Sciences – Hochschule Ostwestfalen-Lippe - in Detmold, Germany.

# 1 Introduction

„Potentials of Additive Manufacturing for facade construction“ is the subtitle of this paper. The Additive Manufacturing processes – also known as *Rapid Prototyping, Additive Manufacturing, Rapid Manufacturing, Solid Freeform Fabrication, Layered Fabrication, and other* – directly link idea and product. *Additive Manufacturing* (in the following: AM) as well developed from idea to product, even to a way of manufacturing, over the last thirty years. In the mid-eighties it started with the wish of product designers to directly translate 3D files into physical prototypes. It all begun with light curing polymers with no reliable materials whatsoever, and developed to a technically sophisticated version of „file-to-factory“. Even today the pace of evolution in this field is so high, that no-one can predict where it is all heading. Applying AM is already everyday business in some industries, in architecture and building construction it is dreams of the future. Especially in this new field of application the presented research work aims to reveal the potentials of AM - to design for function and not to design for production – „Funktionales Konstruieren“.
For AM three-dimensional computer data form the basis for the manufacturing process. The components are designed and planned in the computer. For manufacturing, the data is then translated into a special computer language and generated with AM systems, layer by layer [1]. By doing so, geometries can be realized, that are impossible to be manufactured with conventional tooling. The AM technologies differ significantly from the conventional ways of subtractive manufacturing, like drilling, grinding, turning or milling [2][1] - where material is being subtracted. The materialization is done "tool less", that means, no extra tools, molds or dies are needed for the process. [1], [3], [4], [5].

The principle of additive manufacturing applies to all of the more than twenty currently available methods: special computer software breaks the CAD created 3D model down into layers. These layers form vertical layers/building plans/foot prints of the model. The breaking down process is called slicing. The AM output device (to be named 'printer' from here on out in this article) works through each layer of the model consecutively. Depending on the method, this is done by either exposition, heating, or printing in a process chamber. One single model can consist of several hundred layers, depending on its size. The layer thickness is defined by the resolution of the AM system used; it varies from several tenth of a millimeter down to a few microns. Once the building plan for the model has been worked through, the completed model can be taken out of the machine.
If one compares AM with conventional printing methods, each layer corresponds with one page of a document to be printed. The only difference being that you do not print on paper and not exclusively with ink. The finished product is a physical, three-dimensional rendition of the virtual computer model.
In order to generate a 3D model, a third, the vertical Z axis is needed in addition to the two horizontal axes (X and Y). Movable print heads or redirected light beams extend across the horizontal extension of the model. Building the model up in direction of the Z axis is done by incrementally lowering the work platform. (c.f. [6])

With AM it is possible to generate all different kinds of geometries from virtual data, and to transfer them into reality. All materials used by AM processes mimic the well-known standards of plastics and also a large variety of metals used in fabrication. From the vision of materializing virtual ideas to discuss them on the item, a whole new world of product development has derived. The opportunity to design for function offers to the designer the possibility to think about performance and properties instead of trying to realize his idea with the existing products, as it used to be over the past hundred years. This shift in thinking turns the way of designing upside down. It is no longer important to design for production, but it becomes possible to design for function.

[1]: ASTM International Committee F42 on Additive Manufacturing Technologies: "AM: ~ process of joining materials to make objects from 3D model data. Additive Manufacturing (AM) as opposed to subtractive manufacturing methodologies. Usually with AM parts are processed layer upon layer. Synonyms: additive fabrication, additive processes, additive techniques, additive layer manufacturing, layer manufacturing, and freeform fabrication."

## 2 Short History of Façade Construction

For the last 20.000 years humans built habitats for either cultic or living purposes. Roughly speaking, our architectural environment emerged from there, little by little, up to today's level of development. According to this progress the constructive details appeared – caused by problems people ran into and solved with the knowledge and know-how that was available at the time. Also openings were introduced, either to get in and out or to allow for lighting and ventilation, and most importantly, the demand for amenity values, starting from simple openings, to light frame constructions to the actual window, and at the beginning of the twentieth century to the façade as a separated part of the building envelope.
With this evolution also specialization took place: from covered openings to windows with moving parts; from single-glazed curtain-walls to mullion-transom-systems, later unitized facades; from the rural enclosure of the building to the vision of an integral building skin, that offers a comfortable and energy efficient building. Defined in the 1970th by Mick Davis it was called the "Polyvalent Wall". As an intermediate step the double skin façade came up, afterwards decentralized units, but still the vision has not been reached. [7]

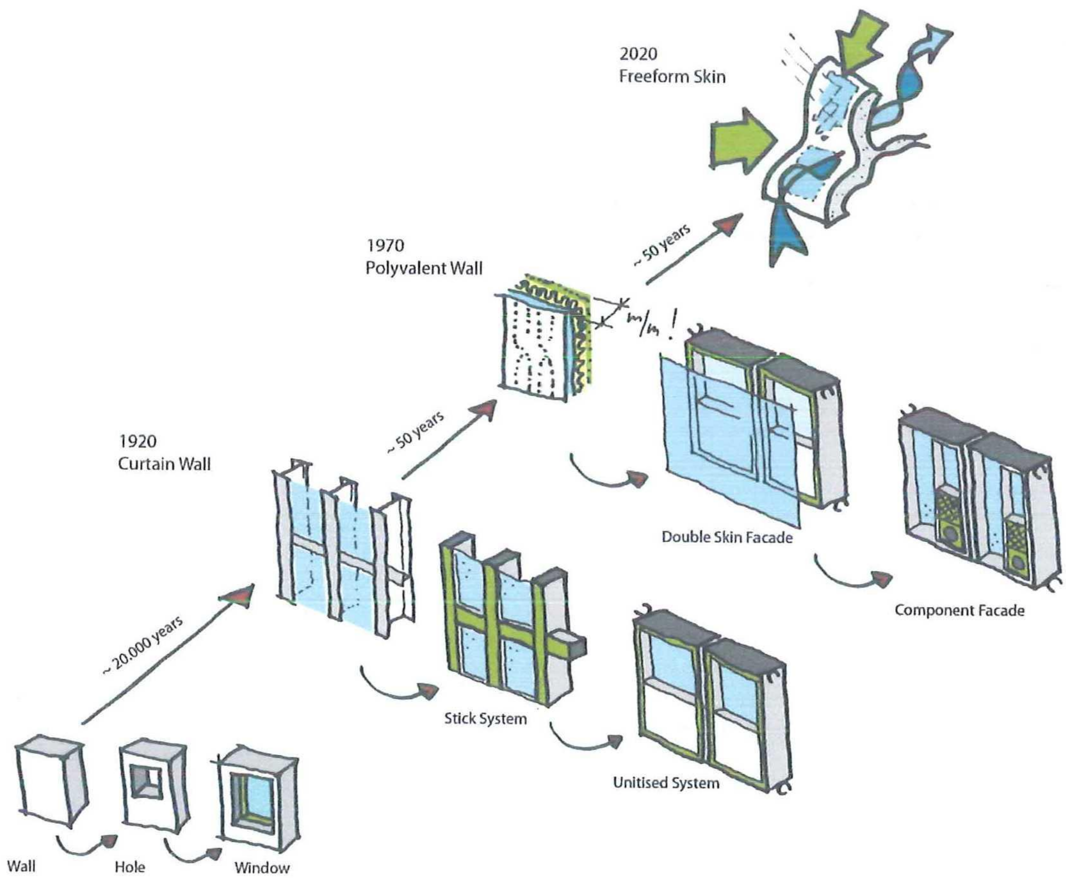
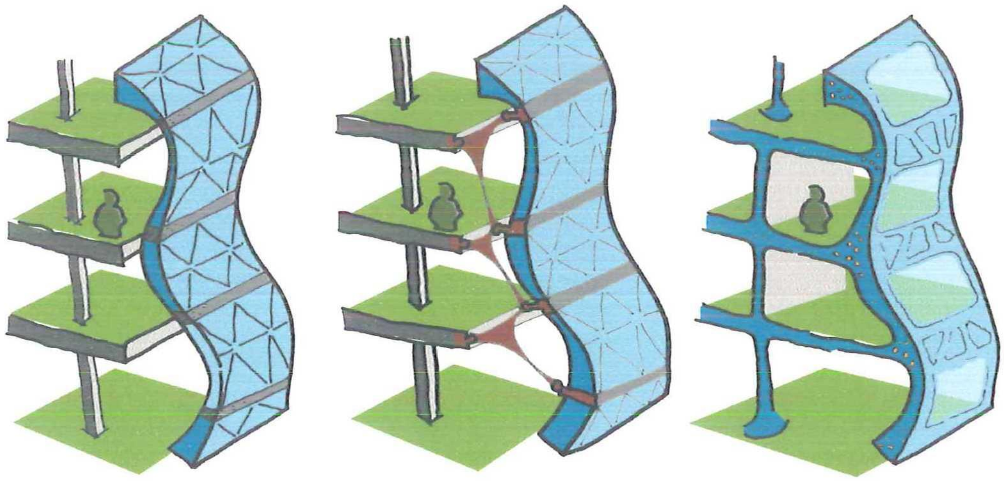



Fig. 1: Evolution of the Building Envelope

Every period has its milestones: from handsaw came the circular-saw by inventing the steam machine; the smoothing plane developed to a planning machine – from here on dimensionally stable parts were produced, that allowed to build windows with turning sashes etc.; from straight edge and pencil derived the CAAD systems (Computer Aided Architectural Design), enabling digital and networked planning – one can even talk about the time "before grasshopper" and the time "after grasshopper", to explain the immense changes that occurred in architectural design since ever architects started to script; from serial production it went on to parallel production, and with this the attempt towards a transition-free "file-to-factory" production chain that produces precise structures in 1:1 scale from digital data – and here we are today, new technologies are pushing the limits. 90% of the digital design is realizable with the available manufacturing processes, the remaining 10% are being reduced by further inventions, and in those we find Additive Manufacturing.

By applying AM it is possible to design parts that offer enhanced joining mechanisms and bear functional parts. It is not at all about substituting the well-known and approved façade systems, and not about seeing AM as an universal remedy with which we can easily "3D print" our facades and our buildings. But critical points and constructive details that bear the opportunity to be enhanced need to be smartly re-designed with the newly available technologies. It is not about printing standard profile geometries, but maybe it is about printing the critical nodal point to join different profiles for a tilted roof with different angles (e.g. jack rafter). Such a nodal point, designed with AM looks different, but offers an optimized solution with fewer members in the joint, less material consumption and an improved way of mounting, so with less labor involved. A step forward, this might change to "3D printed" façade element with all needed connections and fittings.

## 3 AM Envelope – New Technologies for facades



a.) b.) c.)

Fig. 2: Applying AM in architectural design

Witnessing the more and more free-form designs of the latest building projects, one has to ask the question how dedicated those approaches are being realized. What does the future user of those buildings expect? Does a freely formed secondary structure influence the primary structure, as well? Or is it, at the moment, more about shaping forms according to the "*zeitgeist*", only covering standard buildings with free-form facades (Fig. 2a.)? Does new technology enhance the way of connecting and detailing façade construction (Fig. 2b.)? Or does it finally lead to a re-interpretation of the built environment, as we know it today, towards an integrally developed habitat (Fig. 2c.)? The closest application of new technologies is always to fix problems from the existing, far developed standards, but seldom it's about basic re-thinking of the potentials such a technology bears. By doing so, we risk losing the chance to explore those potentials, as already the problem comes from outdated thinking. To neutrally judge inventions those outdated thoughts have to be overcome, the future user and consumer have to be aware of changes according to inventions.

## 4 Research in cooperation with the Industry:

The research-project "*Influence of additive processes on the development of façade constructions*" was conducted on the background of expected changes from AM for façade constructions in cooperation between Kawneer-Alcoa and the University of Applied Sciences - Hochschule Ostwestfalen-Lippe [8].
The façade, being a critical interface of the building, offers a multitude of starting-points for optimisation. With this project first steps were done towards an industrial application of AM for

façade constructions. The results show up on the one hand in 1:1 scale models, enhancing existing façade systems, but also in detailed insight into chances and limitations for AM in façade systems.

### 4.1 Starting points:

As a starting point four different aims were defined at the beginning of the work:

1. Semifinished-Products-Level
2. Element-Level
3. Component-Level
4. System-Level

To limit the number of expected results, the developmental steps conceivable today were divided into time periods. An initial time span of one to three years, where results are immediately realizable with existing technologies (Semifinished-Products-Level); another time span of five to ten years where conceived results are realizable in the foreseeable future (Element-Level, Component-Level), and finally a time span of twenty-five to thirty years which encompasses visions that, with our current knowledge are not yet realizable (System-Level).
With help of this categorization a direct connection can be drawn between today's production and future requirements for modified product design. What begins with a mere optimization of standard components produced with current production methods, will, over the course of the project time span develop into a visionary approach for holistic façade solutions – towards "dynamic envelopes". [2]

### 4.2 Aims and results:

The study started with a scan of the used parts for today's production (Product-Part-Level). Here only some examples out the range of all existing parts were looked up upon closer. Mainly driven by the expertise of the project partners, the parts were selected on the background of sales-aspects, production aspects and their history of development within the company. It was agreed at the end of the study, that the near future invention of a Façade-knot (Element-Level) should be presented to show the state-of-the-art of AM in metals today.

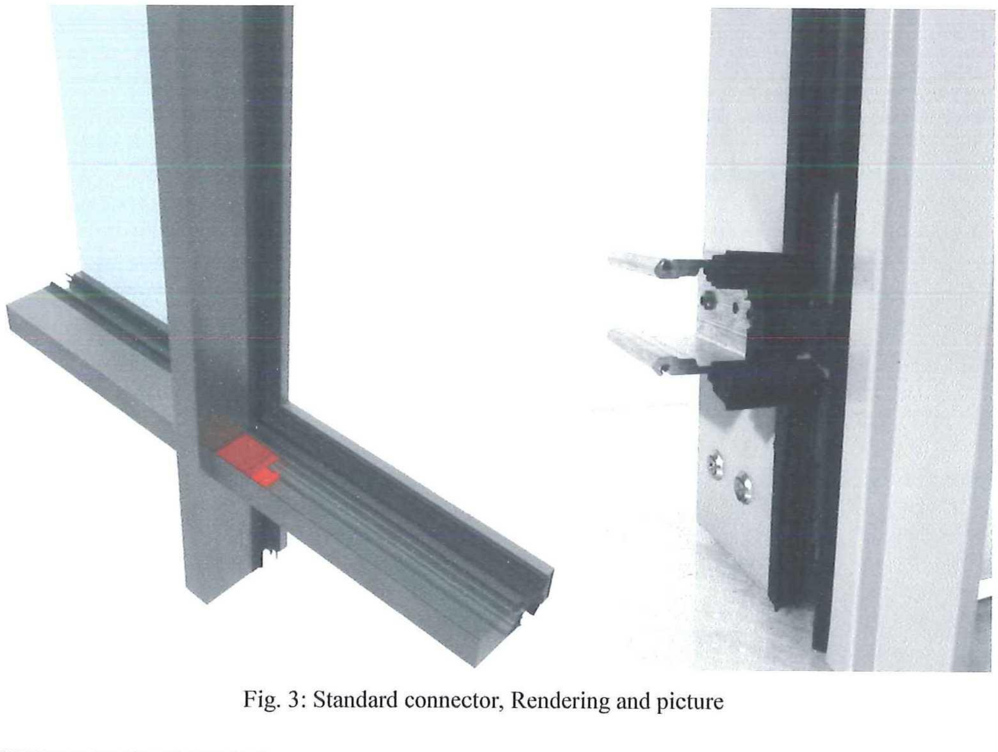


Fig. 3: Standard connector, Rendering and picture

[2] Citation: „dynamic envelopes", Jeroen Scheepmaker, Product Manager, alcoa architectuursystemen b.v., Harderweijk, 10.03.2010

The future impact of AM on façade constructions became clear early after starting the project. But also it showed after some time, that bringing results to a convincing level was more time consuming than expected!

One result of the research project is an optimized connector for the Kawneer "AA-100" stick-system which in combination with digital planning of complex facade structures offers a customized yet assembly optimized solution. (Fig. 3, 4)

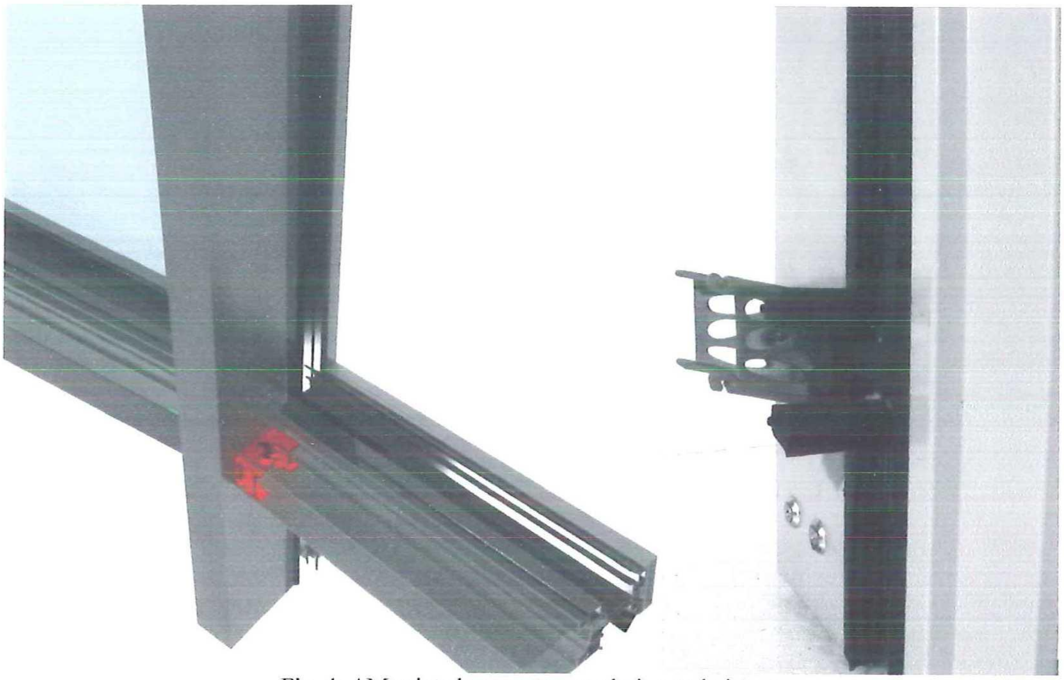


Fig. 4: AM printed connector, rendering and picture

All angles and borings are digitally integrated through manufacturing with additive methods, therefore customized and accurately fitting connectors could be generated for each joint connection. Additional optimization through material savings and force path optimized shaping offer added value that can be realized even for such small details. Assembly is done in combination with standard stick-system sections, all of which can be pre-manufactured with CNC milling equipment with exact angles.

From this enhanced part, the starting point for the next goal was developed: to digitally design and additively print a nodal point for the same facade system – **the Nematox II**.

This part bears all the advantages from the "digital connector", pushed even one step further. The result is a nodal point that meets all the requirements for direct fabrication with AM: the size meets the today available building envelopes of most AM machines, the material used is Aluminum, a standard material for "Direct Metal Fabrication", it was designed digitally and the 3D-CAD-file was directly used to produce the Nematox with an EOS-DMLS-System (a printer that uses metals for manufacturing). (Fig. 5)

By virtually fusing mullion and transom all additional profiles for mounting the façade only need 90° cuts, and therefore ease the difficult situation at both the workshop and the construction site. While, until now, sections and cover strips had to be manually adapted to non-orthogonal angles. The façade can be pieced together easily, because the individual parts could have unique digital identifiers. Due to ever increasing demands in terms of tightness and thermal transfer, the development of sections over the past years has led to increasingly complex node solutions. When eliminating the need to connect at node level and connecting parts outside of this "critical zone" where all seals, water ducts and fixings come together, the potential for defects is greatly reduced.[8]

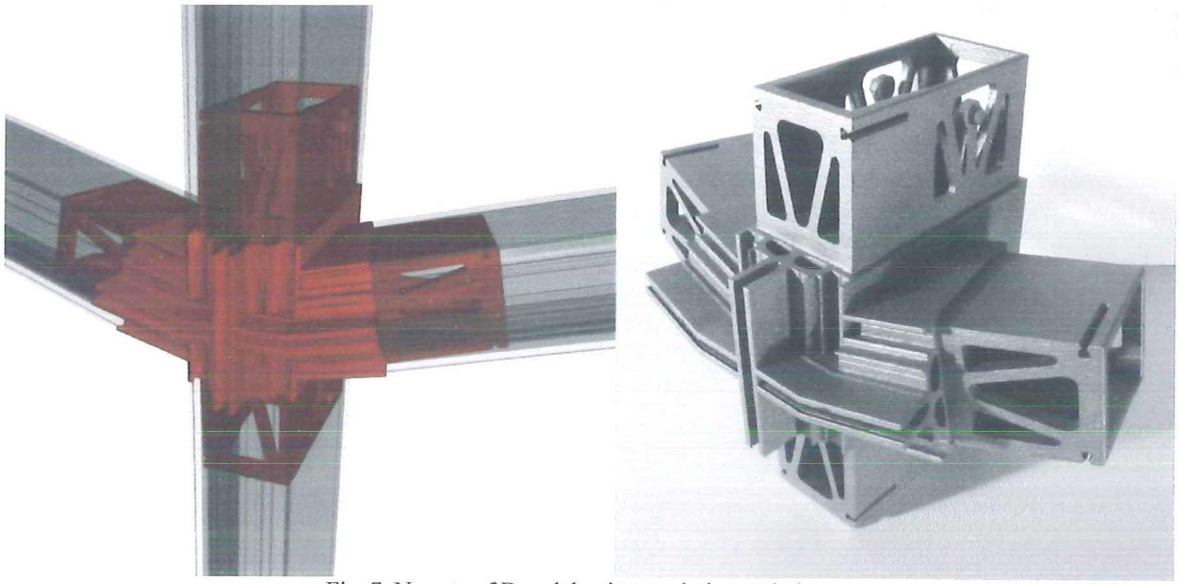


Fig. 7: Nematox 3D nodal point, rendering and picture

# 5 Potential of AM for building envelopes:

With the availability of additive methods one more link is introduced into the chain of true "file-to-factory" production. In an ideal scenario, a CAD-CAM production process would follow the digital planning stage. This would enable us to create parts of a free-form façade with all involved angles and adaptations. All features and performances are directly transferred into the part, also raw data could be the basis for refurbishment or reconstruction projects – e.g. a scanned image of an existing building could be perfectly covered with a new façade. By digitally transferring information into parts, deformed or free formed geometries could be realized at the same quality level of an orthogonal solution with standard products. A system-fit execution of all seals without the need to cut non-orthogonal angles on-site and add silicone could be one result. A unique allocation of the digitally cataloged parts together with smooth logistics result in optimized time management and reduces incalculable additional expenditures. [9]
Digital design and traditional craftsmanship join forces towards a new alliance in *digital craftsmanship*.

## 5.1 Materials

For the application of AM in façade constructions the metals are first choice in materials selection, as their properties are well-known in the field of building construction.
But still it has to be stated that all AM materials are specialized mixtures for a very special technology. All manufacturers try to indicate and meet properties from standard materials known from mass-production, but still they remain "standard-like" materials, and therefore cannot be easily transferred into building construction. Therefore another big request is to develop materials that are suitable for long-term exposure in façade constructions – in both metals and plastics. If thinking about wishes and visions, even new AM systems and materials like glass ("Direct Glass Fabrication" [10]), wood and concrete would make a perfect completion to the existing ones.

## 5.2 Quality standards

No quality standards or norms have yet been established for products produced with Additive Manufacturing. A catalogue of traceable criteria must be developed so that products can be compared to each other and to conventional mass products. A rating system for the parts manufactured, quality standards for the available methods and materials as well as quality control for the individual methods are key requirements when developing a mutually accepted manufacturing method. [11]

When thinking about usage in building construction / facades "General Technical Approval" has to be reached for the AM products. Only if the developed solutions can be applied doubtless of their feasibility for any situation they will become "State-of-the-Art" in façade technology. Certified properties and with this secured liabilities need to be reached for the processes. [8]

### 5.3 Conclusion

Even if manufacturers, users and developers show great doubts when discussing the soundness of those "wild visions", still these technologies have a future in the building industry. They will have a long-lasting impact – however, maybe it will take another ten years. But following the vision of AM Envelopes changes in performance will occur, the wish for truly adaptive facades will be fulfilled, and also Mick Davis' idea of the Polyvalent Wall is becoming more concrete. The approaches described in this paper are sufficient reason for the involved researcher to push the development – if, for the time being, only in principle.
As a result of workshops, seminars and research activity it can be stated, that a wide field of possibilities lies behind the current limitations of AM. The change in thinking has long begun – file to factory, building integration modeling, digital materials, these are first buzzwords, real results have been presented. The technical evolution of AM technologies runs on high-speed, and due to that the intuitive application of AM is predictable. The technologies must be modified by others, but maybe a stimulus can be created for further development and broader use of the enormous possibilities.

Designer and architects no longer have to "design for production", but have to "design for function" [3]. This change turns the well-known world of engineering upside down that was established over the last decade. [12]

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