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Manufacturing processes of complex shapes and structures using 3D printing and augmented reality

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Abstract

The paper describes and evaluates the design and manufacturing process of complex shapes. A parametric structure is designed on the 3D-model, its shape is evaluated on the 3D-printed model, and is manufactured on a 1:1 scale using augmented-reality (AR). The following questions arise: where are the limits for 3D-printed shapes and the limits for implementation using AR? The 3D-printed model will be used to test and evaluate the structure. Using the HoloLens with Fologram software, an attempt is made to recreate the structure with high precision. This process is tested as a hypothesis based on the quantitative, practical investigation. The influence of the use of technical hardware and digital software on the precise implementation of complex forms in the design is shown, and how the influence of digitization and related handling in the field of architecture shifts the limit of feasibility and allows new approaches to the formation of forms.

Keywords: Augmented Reality (AR), 3D printing, 3D modeling (CAD), Computer aided manufacturing (CAM), Hololens, Fologram, Parametric

1. Introduction

The construction industry has been strongly influenced by digitalization for decades. This transformation is also changing the requirements for all academic courses of studies dealing with construction planning. New training formats for new digital technologies must be created and transferred into the existing curricula. Against this background, a pool of learning courses (so-called knowledge nuggets) on the topic of digital planning is being created at the Jade University of Applied Sciences and offered browser-based for self-study [1,2]. This idea of a knowledge repository for students is also reflected in the name of the project "AUFLADEN" [3,4]. The project, which will run for 25 months, is funded by the institution “Stiftung Innovation in der Hochschullehre” [5]. A central theme within the project is the digital manufacturing processes of 3D printing and manufacturing using augmented reality (AR), which are ideally suited for the production of complex shapes. Their application and limitations are highlighted in this paper.

Figure 1. left: Logo of the research project – Source: own figure / right: project funding institution - Source: [5] .

2. Defining the limits through 3D printing and augmented reality

In the construction industry, 3D printing in particular has become very important and has already enabled the layer-by-layer production of 3D objects for several years. [6] On a small scale, as a stationary printer, this technology offers enormous design freedom and enables the production of complex geometries in architecture like shown in Figure 2. At the 1:1 manufacturing scale, however, the possibilities of 3D printing are severely limited. [7] The geometry of the built structure must be adapted to the drive and accessibility of the 3D printing robot. Printing is mostly limited to the use of homogeneous building materials. The simplicity of the design facilitates the manufacturing process. However, these manufacturing limitations conflict with the goal of making highly complex shapes buildable.

AR is more predestined for this, at least visually. It breaks down the technical boundaries by expanding the physical world through the overlay of computer-generated content. For this process, special glasses such as the Microsoft HoloLens are used to fill the user's field of view with the hybrid digital environment. [8] It is possible to display the 3D model in reality through the software Fologram [9], it projects the data model from the computer into the physical world through the AR glasses. Rebuilding the superimposed structure is then done in a second step. This fabrication is also subject to limitations. The case study described below illustrates these limitations and thus provides answers to the questions of what limits complex structures are subject to in the manufacturing process through the use of 3D printing and AR.

Figure 2. left: stationary 3D printer / right: 3D printed model - Source: own figures.

3. Case study

This study deals with the design and fabrication of the geometrically complex structure shown in Fig. 3. The tower, created out of a huge number of wooden bars, is generated by means of parametric design. The software used for this purpose is Rhino and Grasshopper. The geometry is projected into the physical world at a scale of 1:1 using the program Fologram in conjunction with AR glasses, where it is adjusted to the final geometry and evaluated. The projection through the AR glasses is done directly from Grasshopper and can be fully controlled through it.

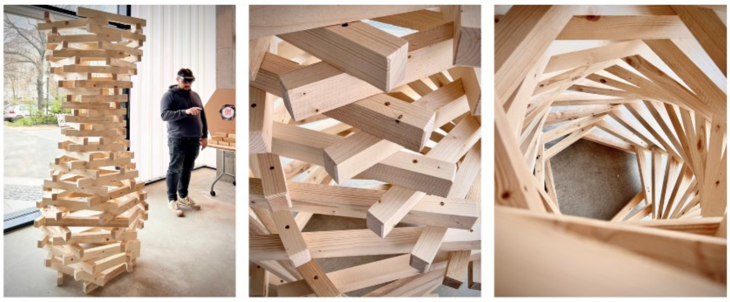


Figure 3. The built tower - Source: own figures.

The design is based on the script shown in Fig.4 Step 1. This part of the script reflects the basic design of the tower. It determines the quantities needed to build the tower. Material dimensions and number of beams are specified here and are scalable by implemented sliders. The script is translated by Rhino and generates the geometry of the tower construction. It can be modified and adjusted by changing the parameters as needed and allows the geometry to be adjusted at any time.

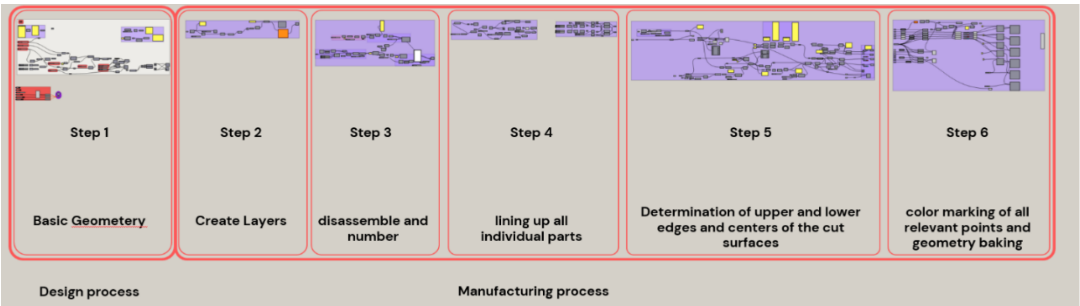


Figure 4. Overview graphic of the development of the case study script in grasshopper. - Source: own figures.

In the next step, the structure is transferred to the AR glasses using Fologram. The geometry is transferred live to the AR glasses with the help of a plugin. The right image of figure 5 shows the projection of the geometry through the user's glasses. The viewer can manipulate the shape using the parameters added in the script. The changes are synchronized in real time with the computer and the AR glasses. This allows the design process to be permanently adjusted.

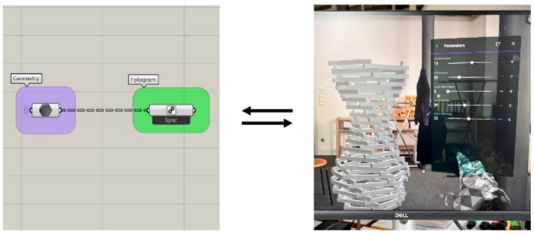
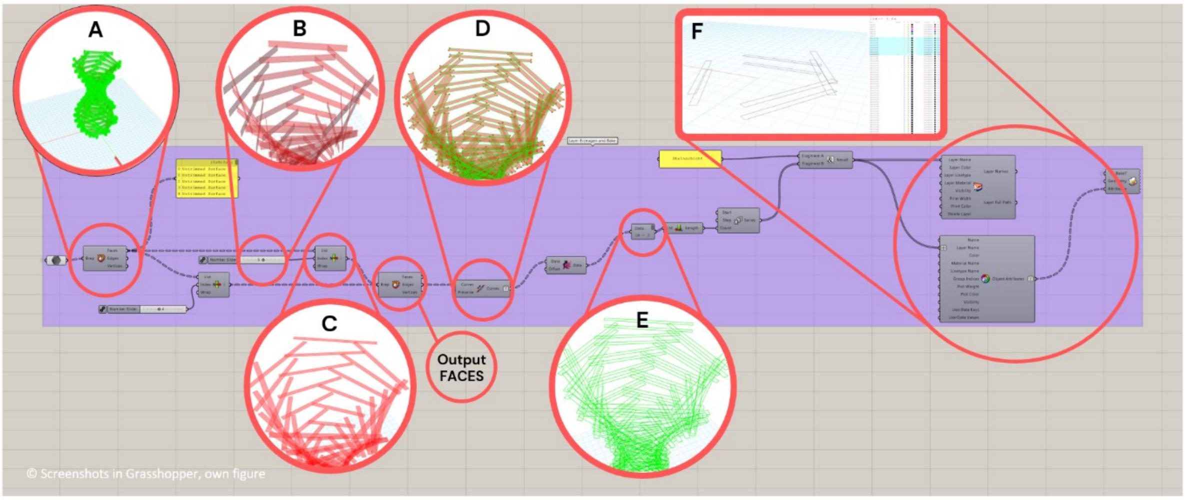


Figure 5. Transmission of the data model through AR glasses and Fologram (Developed by Author)

However, the virtual mapping of a complex geometry alone is not sufficient for the successful manufacturing of a complex structure. Too much information overwhelms the person who is assigned to build the structure with the help of AR glasses. The person gets a virtual three-dimensional image of the shape, but its fabrication requires filtered views of this mass of information. The problem lies, for example, in overlapping lines and surfaces of the wooden bars. Time-related information on the manufacturing process is missing, as well as material information, specifications of fasteners, etc. must be provided as supplementary information to develop AR technology into a tool for manufacturing processes.

This can be explained by the automatic generation of layers as applied in the case study. In the script shown in Fig.4 Step 2, each bar of the tower is placed on its own layer of the CAD software. This enables the fabricator to filter the structure. Thus, only the layers that are to be built during the manufacturing process are displayed one after the other. Furthermore, the script breaks down the bar geometry into individual lines, hides the surfaces of the cuboids representing the wooden bars that interfere with the manufacturing process, and thus significantly reduces the amount of data. Figure 5 shows in detail how the reduction of information and filtering is scripted in Grasshopper. The geometry of the entire tower is broken down into its individual parts using the "DECONSTRUCT BREP" function (Fig. 5: A). The output "FACES" is used to capture all surfaces of the tower. The function "LIST ITEM" (Fig. 5: C) offers the possibility to select the individual surfaces via "INDEX" (Fig. 5: B). The index indicates which of the 6 faces of each box should be selected. In the case of this study, the top and bottom edges are important for the manufacturing process. By changing the index, the other faces of the components are obtained. Then the faces are divided again and connected to form a line. (Fig. 5: D) Thus, a data set of polylines is created. (Fig. 5: E) In the last step, each pair of lines is assigned to a numbered layer. (Fig. 5: F) The visibility of each layer can be controlled directly by the user in the production process.



© Screenshots in Grasshopper, own figure

Figure 6. Simplification and filtering of the complex tower geometry for optimizing the manufacturing process – Source own figure.

In addition to reducing the data through geometry filtering, there is also information that needs to be added. In this project, each bar of the tower was assigned a sequential number, which was displayed with the help of AR and manually transferred to the workpiece. Likewise, the production sequence is a temporal aspect that must already be captured in the digital model through numbering and appropriate sorting of the elements to support a smooth manufacturing process.

Figure 4 gives an overview of how the final program for structure and manufacturing is structured: In Step 1 the geometry is generated. This is followed by Step 2 the layer creation, Step 3 the disassembly and numbering of all components. In Step 4 the components are lined up at an insertion point for later projection onto the workbench. In step 5 the intersection points of the components and their centre points are determinated, the holes for the fasteners are projected and indicated on which side they are located. Finally, in the last step, all relevant information is color-coded in the projection. The enormous programming effort required to support the manufacturing process becomes apparent when you look at the figure. Most of the programming effort has been put into the requirements needed for the manufacturing process. Only one-sixth of the total code is used to create the geometry.

The manufacturing of the tower itself is shown in figures 7. The individual bars of the tower are cut to the correct length. For this purpose, they are inserted into the AR glasses in an orderly sequence, allowing the real bars to be cut to the correct length according to their digital twins. This can be realized by matching the virtual lines with the saw without any additional re-measuring. The bars are numbered according to the program's specifications and pre-drilled with AR support at the positions determined by the script to accommodate fasteners. Afterwards, the AR glasses help with the correct positioning of the bars on the floor and their screwing.

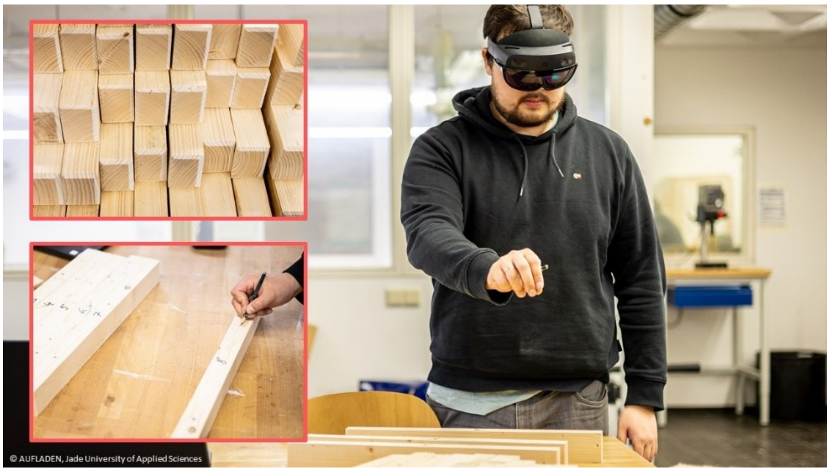

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Figure 7. Overview graphic of the development of the case study script in grasshopper. – Source own figure.

4. Results

The study shown was used to create one of the above knowledge nuggets to introduce students to digital fabrication techniques, the use of AR glasses, specifically using Fologram. The study also highlighted the limitations of fabrication technologies and ways in which these limitations can be pushed further through the programming of supporting scripts. The tower itself and its results were presented at the University's Future:Festival [10,11] in Berlin. For three days, the event addressed questions about the digital future of higher education. The tower itself was on display in the Patricia Lumumba Gallery and accessible to all visitors. It could be experienced in mixed reality through the use of AR glasses provided to visitors on site. Here they could parametrically change the structure and create their own shapes. For those who were connected online, the space also existed virtually and was and still is accessible in the internet [12]. The exhibition combined virtual reality, augmented reality and real reality to showcase the new technologies that are changing the entire construction industry and reports on the limits of digital manufacturing technologies.

5. Resumee

It should be noted that the use of these new manufacturing technologies has greatly expanded the creative freedom of architects and planners. While 3D printing has now become the standard due to its widespread use [6], a focus of research is shifting to the use of AR in manufacturing.

With AR, architects and civil engineers are able to seamlessly transfer digital information into the real world and recreate it there. The virtual model is visualized directly on site and improves communication, minimizes errors, reduces costs and optimizes the manufacturing process. These and other results were generated during the creation of the knowledge nuggets mentioned above and are summarized in this paper. The results are based on case studies that explain the practical applicability and their limitations in the manufacturing process. In addition, it is worth noting that the design and manufacturing process is evolving. Certain skills are required to implement the manufacturing process in everyday life. A high level of technical understanding and basic design knowledge is required to be able to transfer the described process of the case study to other parametric structures. With regard to these new findings, parallel to building with AR, the design process in architecture with artificial intelligence (AI) was examined as part of the aforementioned research project. With the support and free use of browser-based text-based AI's, the assumed knowledge required to implement the design and manufacturing process to other parametric shapes and structures can be expanded and the gap between beginners and experts can be reduced in the future.

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