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INVESTIGATING THE USE OF AUGMENTED REALITY IN THE DESIGN FOR ADDITIVE MANUFACTURING

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ABSTRACT
Additive Manufacturing (AM) has a great potential of disrupting product design and supply chains in many industries by means of its unique capabilities when compared to traditional manufacturing. A wide range of designers would like to take advantage of AM to improve their designs, but they need assistance in learning and breaking out of their conventional manufacturing mindset in the early phases of the design process. Therefore, this study explores the role of Augmented Reality (AR) as a tool for visualization of 3D models to be printed using AM. Specifically, it aims to enhance the learning experience of the existing Design Heuristics for Additive Manufacturing using Design for Additive Manufacturing (DfAM) cards which are focused on transferring early design phase-relevant AM-process independent knowledge and capabilities to both novice and experienced designers. In this study, we propose a modification of DfAM cards to include AR markers into the existing card design and hence provide a comprehensive visualization along with the information about heuristics and examples on the DfAM cards. This helps the user to understand the real-world structure of the final printed product before it is being printed. The cross-platform game engine Unity is used for developing the AR models for this research. We also investigate the advantages that Augmented Reality can provide as a visual interface. An expert review is conducted to obtain feedbacks on the developed application and the new design of the cards.

Keywords: Augmented reality, additive manufacturing, DfAM, design, visual learning

1 INTRODUCTION
AM represents a set of technologies that enable physical components to be created from virtual 3D models by building the component layer by layer until the part is complete. AM has been emerging strongly in recent years. Growth in machine sales and increased numbers of equipment manufacturers show how the AM market has been expanding [1]. AM enables the fabrication of products with highly complex design with various functionalities [2-3]. However, design engineers often think in the restrictions imposed by conventional manufacturing or link AM to unrealistic expectations [2]. The awareness of the potentials and restrictions of AM has not been effectively pushed in the minds of design engineers. Moreover, the adoption of AM in the design process often fails due to a status quo in design or limited knowledge of the responsible employees. A sustainable adoption of AM is only possible by means of complete mindset shift of designers and design engineers from conventional manufacturing towards AM [3].
Literature has dealt with education in the field of AM for almost a decade. Since AM has been of growing interest, Geraedts et al. [4] investigated the role of AM in the light of design engineering in three domains: business, research, and education. Loy [5] puts this conclusion into a different perspective, by stating that design educators face a number of different challenges in terms of AM in design education. Pei et al. [6] use a survey to investigate the impacts of early exposure with AM in engineering education and find that a "think-additive" approach early on leads to a full facilitation of the benefits of AM. Simpson et al. [7] and Prabhu et al. [8] conclude in a similar way. In the light of previous and current research, the literature has not investigated the use of immersive technology as Augmented Reality (AR) for the knowledge transfer and education in the field of Design for AM (DfAM).

Currently, DfAM cards are used as a delivery format for transferring AM knowledge. DfAM consists of a set of design methods which optimize the functional performance of the part as much as possible, but also its cost, reliability, and other product life-cycle considerations. Several techniques are used today, such as generative design, topology optimization or the creation of lattice structures.

Visual instruction is an effective pedagogy to improve student learning and performance, which encourages them towards deep learning. Spatial cognitive ability is an important indicator of how much a student benefits from visualization. Visuals in two dimensions require a higher spatial cognitive ability to comprehend, while visuals in three dimensions do not require spatial ability. Visual instruction may be particularly useful for design students due to their training in spatial ability over the years [9].

Against this background, the main objective of this paper is to answer the following research question: "Can AR be used as a tool to enhance the learning of additive manufacturing knowledge using DfAM cards?". Therefore, we aim at using Augmented Reality to upgrade the transfer of AM knowledge and to supplement design learning through 3D visualizations.

2 STATE OF THE ART

Additive manufacturing (AM), also known as 3D printing, is a transformative approach to industrial production that enables the creation of lighter, stronger parts and systems by using computer-aided-design (CAD) software or 3D object scanners to direct hardware to deposit material, layer upon layer, in precise geometric shapes. AM processes use data from a CAD file which is then, in most of the cases, converted to a standard triangle language (STL) file. During this process, the CAD software drawing is approximated by triangles and sliced, containing the information for each layer that will be printed. AM offers unique capabilities when compared to conventional manufacturing techniques, namely shape, material, hierarchical, and functional complexity. It is yet, another technological advancement made possible by the transition from analogue to digital processes. In recent decades, communications, imaging, architecture, and engineering have all undergone their own digital revolutions. Now, AM can bring digital flexibility and efficiency to manufacturing operations [11].

2.1 DfAM methods

DfAM refers to the process of creating a product design that takes advantage of the unique capabilities of AM. DfAM also adheres to the process constraints of the AM technology that will be used to manufacture the product. DfAM is defined by Gibson et al. [12] as the "synthesis of shapes, sizes, geometric mesostructures, and material compositions and microstructures to best utilize manufacturing process capabilities to achieve desired performance and other life-cycle objectives. DfAM methods can generally be categorized as one of four types: general, design guidelines, computational tools, and opportunistic. Opportunistic DfAM methods focus on informing designers about and inspiring designers to utilize the four unique capabilities of AM in their designs. These unique capabilities are namely [12]:

- Shape Complexity: it is possible to build virtually any shape.
- Material Complexity: material can be processed one point, or one layer, at a time as a single material or as a combination of materials.
- Hierarchical Complexity: features can be designed with shape complexity across multiple size scales.
- Functional Complexity: functional devices (not just individual piece-parts) can be produced in one build.

2.2 Design heuristics

Design heuristics or principles are a popular way of communicating design guidance because they are easy to use, quickly communicate the necessary information and are prevalent across a variety of design domains. Implementing design heuristics or design principles is a good approach for providing early-phase Additive Manufacturing knowledge.

A heuristic is defined as "a context-dependent directive, based on intuition, tacit knowledge, or experiential understanding, which provides design process direction to increase the chance of reaching a satisfactory but not necessarily optimal solution", whereas a principle is defined as "a fundamental rule or law, derived inductively from extensive experience and/or empirical evidence, which provides design process guidance to increase the chance of reaching a successful solution" [13]. Design heuristics and design principles are similar to each other, but heuristics typically use less empirical evidence for derivation, are more general (i.e., higher-level), are less formal, and are usually more prescriptive as opposed to descriptive [13].

2.3 DfAM cards

DfAM methods must be delivered to the user in a format that is easy to use and understand. However, it should also fully communicate the desired information. DfAM cards, also mentioned in literature as DHAM (Design Heuristics for Additive Manufacturing) cards, were found to be an effective delivery format of AM knowledge through several literature surveys and qualitative evaluation from industry workshops [14]. DfAM cards that contain multiple modalities were developed by Blösch-Paidosh [14] and their layout is based on synthesis of 77 design heuristics. In the developed cards, there are seven different pieces of information:

1. Design Heuristic
2. Design Heuristic Number
3. Description of the Design Heuristic
4. Design Heuristic Category
5. Image of an Abstract Example
6. Image of an Example from Industry or Literature
7. Corresponding Short Description of the Real-World Example

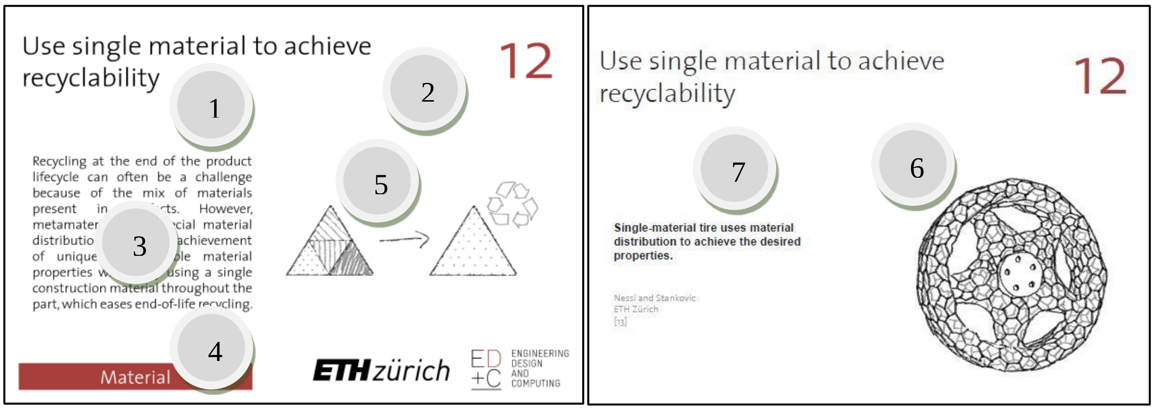

Figure 1. Front and Rear end of the DfAM card developed by Blösch-Paidosh [14]

DHAM delivery format is multi-modal because it is believed that a combination of modes, particularly the inclusion of objects, is the best way to communicate opportunistic additive manufacturing knowledge to the user and to best assist them during the creative tasks required in the early stages of the design process [14]. Text, abstract examples, concrete examples, and objects should all be used. The 2D modalities are organized as a series of cards (one for each DHAM), as using a card deck structures the information in a useful and understandable way, while also making the DHAM easy to use and learn how to use. Furthermore, an accompanying object for each DfAM card was created because it has been demonstrated that providing information in a variety of formats is beneficial, and that doing so helps structure the information in a useful and easy-to-understand manner. Figure 1 shows an example card with all the corresponding aspects labelled. The abstract example on the front of the cards keeps users from becoming fixated on a specific example, while the real-world example solutions on the back help them understand the heuristic in a design context.

2.4 Augmented Reality applications

AR applications can be marker-based, which means that the camera must detect a specific visual cue for the software to retrieve the correct information, or markerless. The most obvious distinction between marker-based AR and markerless AR is whether a marker is required, which directly determines how the relative position relationship between virtual objects and the real world is set. The most important step in developing a marker-based AR application is identifying a marker using the extracted features and superimposing virtual objects in the real environment.

Specific algorithms are required to extract features from the marker and recognize it in order to identify it. Currently there are several AR SDKs on the market that provide these types of algorithms to developers. The algorithms in the AR SDKs can detect and extract features from a marker automatically.

The relative position relationship in the development environment can be set after the virtual objects are linked to the marker (e.g., a 3D development engine or development scripts). The real position of the augmented objects can be changed in the development environment by changing the relative position relationship between the virtual AR camera (which represents the screen on which the augmented objects will be displayed), objects, and markers [15].

3 METHOD

3.1 New design of the DfAM cards

The design of the cards is now improved with the inclusion of the AR marker without manipulating the existing design. Therefore, the current heuristic card was upgraded to a foldable card with the AR marker added to the inner part. The AR marker is scanned with the help of an application which is developed in Unity Game Engine.

3.2 AR Visualization

For this research project, the AR visualization has been created using Unity. The 3D models of the design heuristics were imported to Unity and suitable image targets which displayed robust detection characteristics were chosen as the markers. Image Targets are images that can be detected and tracked by the Vuforia Engine. The Engine detects and tracks the image by comparing natural features extracted from the camera image to a known target resource database. Once the image target is detected, the Vuforia Engine will track the image and seamlessly augment the corresponding content using image tracking technology.

Vuforia Engine is an Augmented Reality software development kit (SDK). Developers can easily add advanced computer vision functionality to any application, allowing it to recognize images and objects as well as interact with real-world spaces. Vuforia Engine supports the creation of AR apps for Android, iOS, Lumin, and UWP devices. The Vuforia Developer Portal is utilized for generating license keys and for creating suitable image targets. A license key is generated using the license manager of Vuforia developer portal. This license key is then copied from the portal and pasted into the project in Unity. An Image target is created using user's Vuforia target manager portal. For this, an image with good features (rich in detail, good contrast, no repetitive patterns) is identified and then imported to Vuforia target manager. Files which give a 5-star rating are preferred for best results. A database is generated using the Vuforia target manager which is to be imported into Unity.

4 RESULTS

The application was installed on a Tablet with Android version 9.0 and was used to scan the AR markers printed on the newly developed cards to display the 3D models related to the heuristic. The new foldable design of the DfAM card is shown in the figure 2a. In the figure 2b, AR visualization for different design heuristics for Additive Manufacturing is demonstrated.

A YouTube demo video showing the AR visualiSation can be viewed under the following link: https://youtu.be/9MxIvgcQ18k.

The models were tested and evaluated by four design experts in Additive Manufacturing and Design Education field. The design experts were chosen as the candidates to obtain a professional outlook and opinion about the application, since they had experiences ranging from 3-10 years in the field of the Design of Additive manufacturing products and DFAM education. The candidates were familiar with AR experiences through gaming, interior design simulation and using AR for recreating internal parts of machines etc. The application was tested by the experts on an android tablet device with android version 9.0 and their feedbacks were assimilated. A questionnaire was prepared which focused on the feedback about ease of use & interface of the application, design of the new cards and using AR for design and for knowledge transfer.

Figure 2a. The new foldable design of the card with the exterior heuristic side (left) and interior side with AR marker (right)

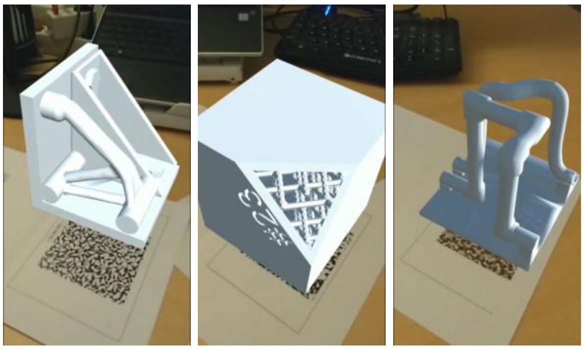

Figure 2b. Visualization via AR application of design heuristics topology optimization (left), lattice structure (middle), part consolidation (right)

The questionnaire is as follows:

1. Have you used AR apps before? If yes, could you mention details regarding the area of use.
2. Do you think AR is a useful tool for design? Can it be used to improve deign education? What are your thoughts?
3. In your opinion, what are the pros and cons of using AR as a tool to improve the learning experience in Design for AM?
4. Does this AR application help to understand the design heuristics (design principles) better? Express your opinion.
5. Based on your experience with the “AR 4 DfAM”, please evaluate the following parameters:
   - Ease of use of application
   - Interface of application
   - New design of DfAM card
6. Do you have suggestions to improve this idea or a complementary approach for making AM knowledge transfer better?

The experts had a positive outlook on the scope of AR and its applications as a demonstration tool and using it for improving design education. Regarding the use of AR for design, they were of the opinion that it can be used as a visual tool for exhibiting design and 3D models to clients. The experts found the AR visualization to be quite useful and helpful in understanding the structure of the complex 3D models and for comprehending the design principles. All candidates were satisfied with the ease-of-use and interface of the application and found the transitions from one marker to the other was smooth and seamless. They agreed that using AR for supporting design education would help in making self-learning an enjoyable experience and would be a great tool for teaching additive manufacturing principles to novices and beginners. They also provided some valuable suggestions like the idea of adding an AR marker for creating a visualization for conventional models along with the optimized additive manufacturing models, in order to make a comparative study. They also proposed to incorporate colours to highlight the optimized 3D model parts to make the visualization more appealing. The feedback and suggestions were quite insightful, and those inputs were evaluated and included into the new version of the app.

5 CONCLUSIONS

This research project aimed at enhancing the learning experience of Additive Manufacturing knowledge for novices by adding an augmented reality visualization to existing design heuristic cards. It can be described as a modification or extension to the DfAM cards where the cards are re-designed as foldable cards with the AR marker added to it. The AR visualizations were created using Unity and it was built and tested in Android 8 & 9 versions.

The AR visualization helps the user to understand the real-world structure of the final product to be printed and can be very useful for demonstration and learning purposes. Visuals play a crucial role in design education and the idea of upgrading to a visual platform from a paper-based platform were appreciated and well received by DfAM experts. Since the study was carried out with 4 candidates who were design experts, a similar way of thinking was observed from their opinions which could be different from a non-expert candidate group. Investigation with this type of group is to be carried out in the near future. Nevertheless, the current validation of the developed app provided astute observations and suggestions for improving the user experience.

This research project will be the basis of further research in developing a head mounted display visualization for enhancing DfAM knowledge transfer. Upgrading to head mounted display (for e.g., Microsoft Hololens) would hence make it a state-of-the-art technology used for DfAM knowledge transfer.

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