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Democratised Making

Skills enhancing through Extended Realities

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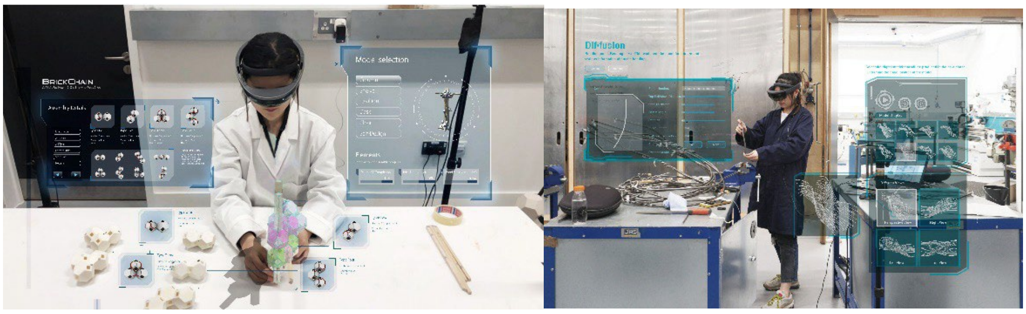

Fig. 1. Left, BrickChain project. Right, Diffussion project.

PART 1: PROPOSITION

ABSTRACT

Throughout history, technology has had a crucial influence on the development of our society. Different eras have been defined by sets of technological advancements, which at the same time had a profound impact on the built environment and construction. It has been proposed that, after the internet age, we are entering a new era - the 'Augmented Age' (King, 2016), while physicist Michio Kaku argues for the future in which architects rely heavily on Augmented Reality technologies (Kaku, 2015). Machines have become an inseparable part of our daily life. We are immersing ourselves into rapidly developing mixed realities, with portable devices (smartphones, tablets etc.) augmenting our perception of the environment. Barriers between humans and machines are increasingly blurred, and the modes of interaction between them becoming progressively sophisticated at a rapid pace.

The future of manufacturing jobs will be embedded with technological add-ons that will augment the capabilities of the workers. This augmentation will come from the XR devices, including (Augmented and Mixed reality) and human-machine collaboration and automation. This relation between technology and human labour will have a high impact on architecture. It will change the traditional roles in the production chain, affecting everything from the way we design to the ways we manufacture. Concepts like designer and artisan are again brought together through Immersive technology. In the same way, the barriers between user and designer are continuously diluted through these technological advances. This paper reflects on the current state of XR technologies in architecture and how they will influence design and production.

KEYWORDS

Augmented reality, Skills democratisation, Machine Learning, augmented manufacturing, design automation.

1. INTRODUCTION

As described by King (King, B. 2016), the Augmented human will be the future. This human will enhance his skills and capabilities by augmenting himself through technology. There will be probably two main ways of augmentation for the future worker. The hardware that will consist of mechanical devices the human will attach to his body, like mechanical exoskeletons, will increase an individual's strength or performance. The second set will be augmenting devices, which will be the sensorial ones, the Extended Reality.

Different types of devices can be used for AR/XR, but there are mainly three different categories: environmental, tools, and wearables. The first category contains elements like interactive projections or actions related to the human sensorial system externally. The second category, tools, is related to all sorts of devices a human can use to extract more information from reality, like HUDs or smartphones. Those devices do not affect the sensorial perception, but they expand the information around the user. The third category is about wearable hardware that can both extend the data from the environment for the user and interact with the sensorial perception.

2. OVERVIEW OF EXTENDED REALITIES

Extended Reality (XR) is an umbrella term that covers Virtual Reality (VR), Augmented Reality (AR), Mixed Reality (MR) and other immersive technologies. This technology group allows for different modes of interaction between humans and machines in real and virtual environments (Figure 1). Various media can be used to achieve this, with the requirement that the digital device must alter the usual understanding of the real world by the human (Milgram, P. and Kishino,1994). Usually, those changes will enhance the vision of reality but sometimes can perform the opposite by limiting or degrading the inputs perceived by the user. Milgram and Kishino classify the intensity of immersion into six classes depending on the interaction level and the intervening hardware: 1. Monitor based - non-immersive, 2. Video displays using head Mounted Devices - HDMs - rather than monitors, 3. HDMs with see-through capabilities - which superimpose computer-generated graphics with real-world environments, 4. Same as 3, but using video rather than optical viewing of the outside world, 5. Completely graphic display environments, either completely immersive, partially immersive or otherwise, to which video "reality" is added. 6. Completely graphical but somewhat immersive environments (e.g. large screen displays) in which actual physical objects in the user's environment play a role in (or interfere with) the computer-generated scene, such as in reaching in and "grabbing" something with one's own hand.

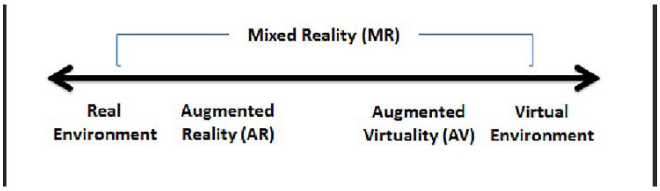

Fig. 2. Figure 1. Mixed Reality Continuum

3. PREPARE YOUR PAPER BEFORE STYLING

Traditionally architecture is a field that is very slow in adopting cutting- edge technology. Evolution has been very slow, and the technological situation in the construction industry has not significantly changed since the last quarter of the 20th century (Claypool et al., 2019). Despite early examples of the use of different AR sources having been made during the previous 20 years within the research environment, only very few have found its commercial application. The earliest professional application of this type of technology might be related to the conservation and restoration of heritage buildings. Projects like Timeframe (Belgium,1997) or Archeoguide (Figure 2) showed the potential to use overlapped digital information over the real-world environment. A similar approach can be found in what is probably the first professional example of commercial applications for AR, Trimble Navigation (2004).

Fig. 3. Archeoguide. Display of an AR reconstruction of a Building.

For the first time, this project allowed the potential buyers of a house to explore and interact with the 3D model of the house prior to construction. Due to a very successful result, this concept started a new trend that has become almost mainstream nowadays. (De la Fuente, J. et al, 2017).

These examples are primarily utilising AR as a pure visualisation tool. However, the true potential of AR and another immersive tech in architecture lies in its use in the processes of design and manufacturing. With this in mind, we can classify the application of AR in architecture, and to an extent, other Mixed Reality techniques, into the following:

- Visualisation and visual immersion - HDMs are used to display designs and objects in Augmented or Virtual reality.
- AR assisted fabrication - HDMs are used to display manufacturing data to the user. Fabricators can follow holographic guides in fabrication and assembly, essentially eliminating the need for construction drawings.

- AR assisted design - Designers are able to interact with and change existing designs or create digital models in real-time.

4. AUGMENTED MANUFACTURING

The implementation of Augmentation in the mainstream construction industry is still in development, and very few examples can be found nowadays. Early research about augmented techniques can be found in the Tokyo University Obuchi lab agenda. During recent years, they have been developing a series of proposals of augmented manufacturing like the Toca Pavillion from 2015 (Lopez, D. et al., 2016). The manufacturing of this project is focused on several ways of augmentation, hardware and software. For the hardware, the project uses two technologies. The first and primary tool for fabrication is a bespoke device that connects to the human and deploys the foam used for the construction. The second hardware is based on computer vision. Through QR codes, the computer can read and analyse the deployed foam and follow the building process.

The software augmentation consists of a primitive version of machine learning that reads the QR markers and readapts and recalculates the design according to the human error. The human builder is guided into the choreographies needed to build the pavilion recursively through this method. Although no Augmented reality was used for this project, it shows how augmentation can change the traditional building processes.

To find an example of augmented manufacturing connected to an Augmented reality device, an interesting early example could be the Steam Punk Pavilion (Hanm, S. et al., 2016) for the Tallin Biennale of Architecture. This built structure proposes a method for fabricating complex timber structures created by steam-bending timber 3-dimensional curved timber elements by following holographic templates using traditional crafting techniques enhanced with the precision of digital data (Figure 4). This example has an interesting implication of how unskilled workers using augmented reality can perform highly skilled operations guided by the AR device.

Fig. 4. SteamPunk Pavilion built with the aid of Augmented Reality

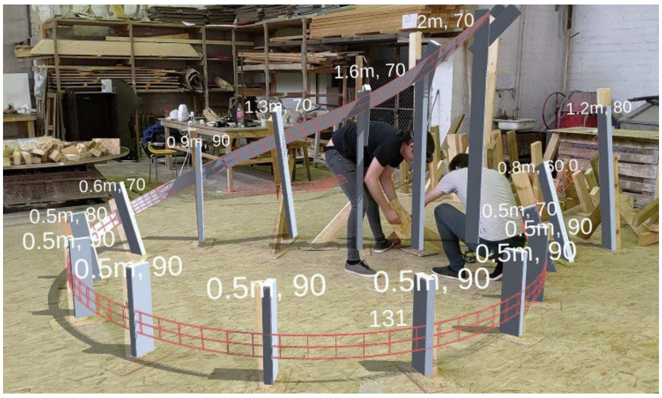

Fig. 5. Figure 4. SteamPunk Pavilion - the process of placing the formwork according to the 3D model visualised through an HDM. Also visible is a holographic guide for bending timber boards.

5. The Democratization of Manufacturing.

The augmentation of the workers in the construction industry promotes a new point of view on what a skill means. As it is shown by the previous examples of early augmentation in manufacturing, the main result of implementing such a technology is the democratisation of building skills. Workers with no prior experience can now access immediate building knowledge and are guided to produce and build components with no previous experience in the technique. That can have a significant impact on the traditional building industry. The current hierarchy of skilled and non-skilled workers can quickly change by removing the need for highly specialised technicians, and therefore, incrementing the pool of workers available for complex manufacturing procedures. In the same direction, as shown by the Toca project, not only guidance but intelligence on the making can be embedded and used to mimic traditional making and enhance it into a new level.

The live guidance for assembly or form-making through augmented methods is an interesting approach to democratise skills for the making. It opens an interesting discussion about the future of the traditional working force. Still, with the increasing availability of AR devices and computer power (King, B., 2016), we should look to not only augment the making but enhance it by adding computational approaches to the system. Design and Making can be closely related by simulating material behaviour and applying machine learning to optimise a process. The following Study cases analyse this potential through a computerised forging system and a Machine Learning based reconfigurable architectural system.

1. Part 2: The Democratization of Manufacturing.

6. Diffussion Project

6.1 Design integration:

One of the main proposals from the augmentation research in Diffussion was to integrate de digital design into the whole system, so a direct connection between designer and maker is achieved, blurring, in fact, the barriers of both roles. So based on this concept, the project uses a generative computational logic to create the design.

The main design algorithm is based on a particle logic that uses “Voids” to control the generative growth within the base space frame. To construct the main lines that articulate the design, the mentioned “voids” run in a semi-random way through a three-dimensional space following the influence of a series of attractors that can contain a positive (attraction) or negative (repealing) force on them. The void can flow through space by guiding and affecting the attractor particles from an origin seed to a target goal.

Two strategies are proposed from the design perspective to control the attractors: environmental and interactive. The environmental one is related to the fundamental goals the structure need to comply with. That means the origin and goal targets, every obstacle in the way or inside the reference frame, need to be avoided, and every additional element that needs to be addressed. In this case, the attractors and rappelers will be fixed and used as the first reference system for growth. The interactive one then contains all the extra attractors and rappelers that can be edited or changed during the design process, but they are not affected by the existing environment. In this case, those particles have been integrated into the augmented reality interface, so the designer can directly interact with them by hand manipulating them in the virtual model. With this design method, the integration between computational and interactive design is direct, and it works in a reciprocal loop.

Once the base frame is generated via the interactive augmented process, the technical part of the design is implemented. This process happens through a second layer algorithm designed to create a series of complementary elements or “branches” that interconnect the main components together, adding structural performance capabilities to the system. The second layer generative algorithm also has the function of surface generation by filling the gaps in the areas requiring user interaction like floors or walls, or in the actual prototype (picture), balustrades for a bridge. The third layer of the algorithm is the joinery logic. A series of adaptative joints are added to every intersection in between elements to connect them. This system is especially adequate because by using a “twisting method” based on the augmented forging technique, the project explores a very flexible, low skill method to create them. The twisting logic also allows connecting any number of elements into the same joint enabling at the same time various directions and thicknesses of bars. As a result, every join can be unique, responding to a series of specific requirements that can allow a full three-dimensional result.

THE AUGMENTED MANUFACTURING:

Based on very traditional forging tools and techniques, the augmented forge method that has been proposed in Diffussion adds a new layer of complexity to the result by mixing the digital production from the generative algorithm with the human interaction in manufacturing.

The first phase in the construction is joinery manufacturing. For this step, all the joints are analysed and categorised depending on the number of elements and directions. Then every bar in the joint is framed in a standard jig to be forged. Once heat up into forging temperature, the maker proceeds to the twisting process guided by the holographic google and the projection of the exact number of twists and the actual length needed. After the twist is processed, the join is located in another jig to proceed with the bending to achieve the precise direction every bar needs to face. Again, this process is managed through the augmented projection of the actual direction and angle of every end of every bar. After this step is finished, every joint is let to cool down and stabilise. This action is critical since the cooling affects the friction the twisting creates.

Fig. 6. Diffussion Project. Augmented Tools.

The second phase in manufacturing is bar bending. For this process, the augmentation is implemented into two different aspects: the actual bending and the machine to use. For the actual bending, which in this case is based on cold pipe bending, the bending process is computerised and guided by the holographic device. The bending machine is then included in the Augmented reality guidance and computed to generate the specific curvatures needed. Every bar is first categorised by length. Then, the bending process is divided into two stages. The first is the general angle, which integrates step-by-step guidance that allows the maker to precisely bend every bar for the correct curvature by projecting the actual shape of every bar for every step and the calibration of the bending machine. The second stage is the fine adjustment for the three- dimensional bending. This is achieved by locating the bar into a jig so the maker can bend it to the right 3d position by following the augmented projection.

Fig. 7. Diffussion Project. Friction Based Joinery.

1.1 AUGMENTED ASSEMBLY:

The proposed prototype, a bridge, in this case, added the need of defining meta-elements that could be pre-assembled apart due to size and weight constraints. Because of that, in this study case, the assembly was developed in two steps. The first step for the assembly of the meta- parts was also guided by augmented reality projection of the meta part into a computerised scaffolding that would help with the correct positioning of the pieces. The components, bars and joinery were assembled in a specific order defined by the projection, and the elements were chemically welded during the process. Once finished, the part was removed from the scaffolding and store until the second step; then, the scaffolding is adjusted according to the next meta-part.

The parts were first tested for the final assembly phase in relation to the digital projection, and the scaffolding re-assembled into the suitable configuration. The final piece was then assembled using augmented projection, using this same projection to adjust the small discordances produces during the crafting and the first assembly phase. Once assembled, the bridge is compared against the digital model to compare results and check any possible error.

In conclusion, this project shows the vast possibilities of augmented manufacturing in architecture, introducing the idea that non-skilled workers can perform complex manufacturing thanks to the use of augmented devices as a guide for crafting and quality control.

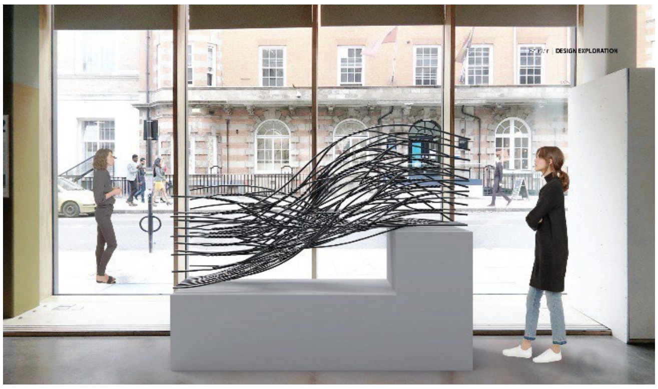

Fig. 8. Diffussion Project. Bridge Prototype.

7. BRICKCHAIN PROJECT:

7.1 DESIGN INTEGRATION:

Human intuition for stability in an assembly usually is accurate enough. The problem comes when de system increases complexity and the assemble start to increase ramifications. In this sense, probably the best way to approach this is to use computational power to solve it. While human brains are powerful with creativity, computers are faster and more efficient with repetitive calculus (Carpo, M. 2017). This idea is the mainframe for the Brick Chain project. In this case, the overall design is based on a reconfigurable set of parts that can be assembled assisted by AR. That can result in several different configurations from the same predefined set of parts.

Two main elements are used to define the set: a ceramic truncated dodecahedron and a square wood bar. Together they form an interlocking system that enables the development of interior space definition. The ceramic component acts as the Joinery System, and it can get grouped into several elements clusters that define the direction of the geometry. The wood bars in this system play the role of space definition and interconnection between ceramic clusters. Together they form a complex assembly system that uses friction and simple screws to stay stable. Since there is no glue or unremovable joinery, the system can be also dismantled and then reconfigured into a new design easily.

The computational design process is defined by a parametric logic that defines the overall space and divisions to cover. Then a computational algorithm based on machine learning can determine the most efficient stable assembly to populate the designated space. The system is biased in the amount of ceramic that is usually reduced to the minimum possible, favouring the number of wood bars within the assembly. Lastly, suppose the designer would wish to edit parts of the proposed design by the algorithm for esthetical purposes. In that case, the computer will adapt them and then recalculate the structure to include the desired changes and assure the stability of the proposal.

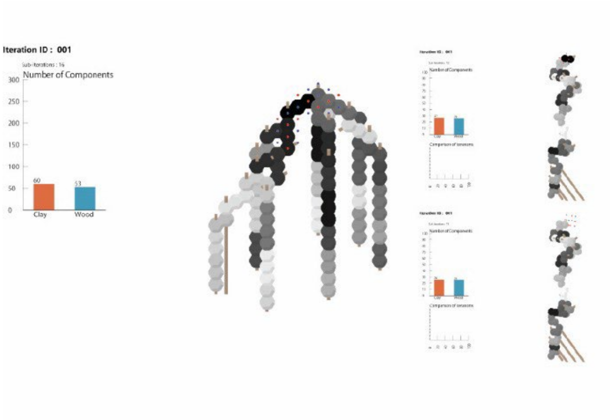

Fig. 9. Brick Chain Project. Machine Learning Analyses.

7.2 THE AUGMENTED MANUFACTURING:

The components for the assembly are designed to be simple and recognisable. This simplifies the assembly process as well as the Machine Learning optimisation. For the manufacturing, the approach is that it should be a hybrid of automated and augmented crafting. For the automated part, mainly the wood bars can be manufacture in a traditional industrial way and then cut by an automatic machine to match the sizes required by the assembly. That facilitates the homogeneity of the connection elements and ensures its structural performance in the overall structure. For the ceramic part, there are two options. The more abundant and straightforward components like the one, two or three components clusters can be mould made in a serial way to simplify and optimise its manufacturing. The other category, the complex, and bespoke cluster, which usually includes more than four components, can be slip cast out of reusable and reconfigurable moulds that can be assembled with augmented reality assistance. The augmented moulding system then optimises the waste of material, allowing a greater number of variations. In this way, combining those two methods allows for a more flexible system that can adapt better to any specific assembly required.

7.3 AUGMENTED ASSEMBLY:

The opportunities of an intricate reconfigurable system are plenty, but they come with a complexity issue for the assembly. The set of parts, although simple, is not intuitive on its construction logic, so augmentation is required. Augmented projections guide the assembly process to drive the builder through the correct order of assembly and the suitable component to assemble. To achieve this, and since many components can be very similar, every component has a unique pattern that works similarly to such a QR code. Thanks to this pattern, the computer can recognise every block using machine vision through AR goggles. Also, this pattern is designed with an aesthetical purpose so that it can be functional and pleasing. The wood elements are normalised in several dimensions so that the assembly notation in the projection can quickly identify them.

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Fig. 10. Brick Chain Project. Computer Vision System

The assembly logic, which is also embedded with stability intelligence, is based on stages, so the project is assembled by sections and then connected altogether. This concept facilitates the assembly and allows for a minimal level of scaffolding. This simplicity is intentional, so no special skills or building experience is required, giving more users the opportunity of access to the use of the system. At the end of the assembly, the patter of the ceramic clusters is used again to read the overall structure and therefore calculate the achieved accuracy of the building. This can then be used as a way to certify the stability and the security of the built project.

For the reassembly, a similar process must be conducted. In this case, the assembly can be analysed from the saved project data or by scanning the components patterns to calculate the dismantling process and define the elements available for the new assembly. Once the data is calculated, a new series of parametric parameters can be determined, and a new design could start following the previous logic.

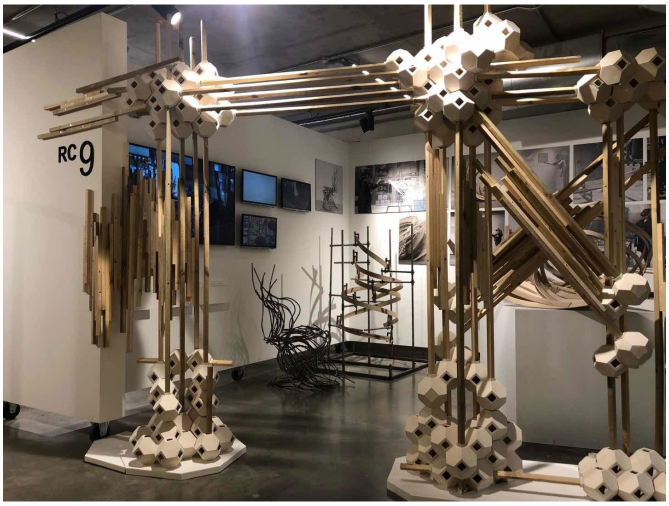

Fig. 11. Brick Chain Project. Spatial Assembly.

8. CONCLUSIONS:

Augmentation in architecture is still in its early stages; the technology, although interesting, is still not completely developed, so improvements are to be expected. The upcoming years will have an interesting role in developing and defining how XR will change architecture as it is changing other industries. What is clear from the different projects that have attempted to implement it as a tool is that the democratisation of skills is entirely possible. From simple tasks to complex forming methods, augmented reality can help perform procedures that before required highly skilled workers to complete. As shown by the Diffussion and BickChain projects, XR can enhance traditional methods by integrating intelligence and computing power with the worker. It is not only about democratising skills but enhancing human skills for the building process in general. This is probably the most significant potential. Augmentation is based not only on the device but also on a wholesome approach that will enhance our intelligence through computing, our skills through augmented reality, and our capabilities through body hardware (King, 2016).

9. RESEARCH CONTEXT:

This paper is based on the research agenda conducted by Alvaro Lopez Rodriguez, Igor Pantic and Soomeen Hahn at the B. Pro Architectural Design Research Cluster 9. This Agenda is focused on exploring the potential of Augmented Reality in Architecture through 12 months of research projects. The two main study cases exposed here are both examples of the research work produced at the unit by students.

9.1 DIFFUSSION PROJECT

Tutors: Soomeen Hanm, Álvaro López Rodríguez

Students: Teng Wang, Minzhe Song, Danping Meng, Rouxy Lyu, Siwey qin.

9.2 BRICKCHAIN PROJECT

Tutors: Soomeen Hanm, Álvaro López Rodríguez

Students: Ignatius Christianto, I Gede Eka Pradnynida, Changshu Dong, Di Zhu.

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