BloomShell

Augmented Reality for the assembly and real-time modification of complex curved structure

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Augmented Reality (AR) as a new technical tool has developed rapidly in the last few years and has now the potential of bridging the gap between holographic drawings and the real world. This paper addresses whether AR can guide unskilled labour on complex structure assembly and fabrication process. It contains three experiments developed with AR. The research aims to prove that with intuitive holographic instructions, AR helps to reduce the time spent in comparing 2D drawings to the real site during the assembly process, and therefore offers possibilities to improve the construction efficiency significantly. The research also paves the way for shell structures, considering the latest technology such as AR and AI, and gives emphasis on the communication between computer and human during the fabrication process through the physical model. It is an exploration of how people might change their mind or decisions can be changed in a real-time manner harmoniously using AI through AR.

Keywords: *Augmented Reality, complex curved structure assembly, real-time modification, holographic instruction, HoloLens, Artificial Intelligence*

INTRODUCTION

The technologies we are using and exploring today are fundamentally going to redefine the next age of humanity. We are now entering a new epoch called 'Augmented Age' (Brett et al., 2016). At the same time, Augmented Reality (AR) has significantly improved, including the technologies and related devices in recent years (Wang et al., 2016). AR aims to display 3D virtual holographic objects overlapping the real world and to provide the user with the opportunity to interact with the co-existing virtual hologram in the real world.

AR can be used to provide visual information for an existing plan in detail. More generally, AR is used as an interface between digital information and the real world. It has the ability to show the digital pre-design 3D model and fabrication guidance (Giovanni Betti, 2018). Physician Michio Kaku imagined the architects will be relying heavily on AR technology in the future (Kaku, 2015). It opened up possibilities in every aspect of our daily lives, and it is expected that this will have a significant impact on every field in the near future, including design and fabrication. AR deliberates a method by using the aid of high precision and detailed holographic assem-

bly instructions (Chengyu Sun, 2019). Previous research and commercial applications have progressed this model (Soomeen et al., 2019), and it looks into developing technology to ease the working pipeline for AR-based fabrication. The assembly of complex structures required detailed 2D drawings and skilled labour to interpret and operate. This method takes time to compare the drawings with the actual construction by the skilled labour (Gwyllim Jahn, 2019). Researchers mainly focused on showing the 3D holographic projects in the real world and exploring how users interact with them in the previous projects rather than testing a way of applying AR technology to the fabrication process. Therefore, the opportunity now is ideal for exploring the impact of AR technologies on the architectural construction industry and the method of AR technologies on computer and human intelligence.

Contemporary research in curve shell surface has been enormous advancements over the last few years in digital fabrication and automated construction technologies, such as 3D printing, CNC and robotics. Composite Swarn and Minima-Maxima (Figure 1) are the perfect projects exploring the use of the computational method in the design process and construct digitally and robotically in the fabrication process. Although they demonstrated they can control the curve surface precisely in fabrication, those processes are highly dependent on the skilled labours to translate the construction introduction into complexed coding to operate the robotic machines and expensive machines to deal with the errors and tolerances. These projects achieved the accurately restored of the physical model from the digital model. Still, this high technology and high-cost process seem not that economy and not accessible for unskilled labours to achieve. It appears to be a creative way by using material behaviour and low-cost technology to aid unskilled labour in the fabrication process as well as using human and computer communication to reduce the errors and modify the digital outcome in real-time to achieve the design and fabrication of complex curved surfaces.

Figure 1
The complex fabrication process of Composite Swarn and Minima-Maxima project

BloomShell is a research experiment developed in the Bartlett School of Architecture (Figure 2). This project departed and elaborate on the concept of AR Assisted Fabrication for highly complex curved geometry which can be effectively managed manually by the unskilled worker according to its material property. Beyond that, BloomShell designed a unique project trying to find out the relationship between human and computer, especially to emphasize on the communication between computer and human while making decisions harmoniously through the physical model fabrication process.

Since the methods which architects produce the design are no longer expected to be limited to a simple process, this exercise confronts the complexity of using digital and physical protocols to explore the use of adaptive 'unexpectedness' of the digital generative design, relating to previous research on design 'glitches' as a trigger for further critical production and novelty (Austin, 2017).

Figure 2
Augmented Reality
assembly process
and virtual
holographic
information
demonstration:
Project BloomShell

RESEARCH METHODOLOGY

This research aims to find a way of precise and quick craftsmanship fabrication and assembly of complex curved structure without any mould for builders including unskilled labour under the guidance of virtual target holographic introduction in the real world through Augmented Reality.

BloomShell Experiment 1
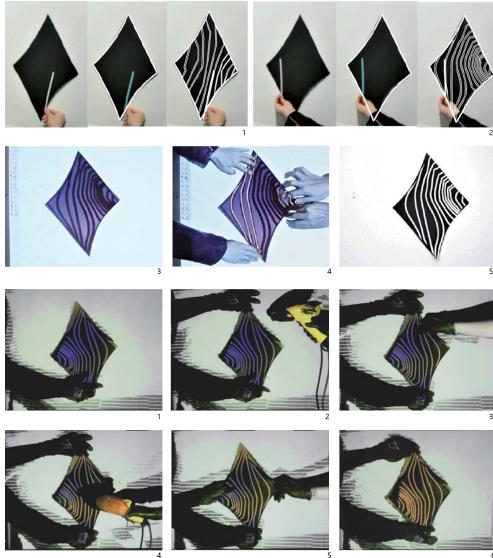### - Kinect and projector system

BloomShell experiment 1 (Kinect and projector system) explores the feasibility of manually curved surface fabrication through augmented information. To achieve that, we need a material which suitable for manual work and easy to operate into curve surface. After several material tests, WBA (Worbla Black Art) plastic is chosen as the main fabrication material. WBA thermoplastic sheet is smooth modelling and moulding material, safe and clean. It will be easy to shape to approximately 80℃ heated by a heat gun. It will be sticky to connect with each other without

other material or joint. It also can be re-used and re-activated at that temperature. The property of WBA meets the possibility of manually surface fabrication and complex structure assemble.

According to the basic concept of AR - overlapping the virtual instructions on the real world, the researcher decided to use Microsoft Kinect and a projector to achieve that. The Microsoft Kinect device was applied to scan the processing model in real-time. The projector was applied to project the virtual information calculated by the computer in real-time on the continuous model surface to show the guidance for builder and unskilled labour.

After the workflow was designed, Kinect will be utilized to identify the material shape and sent it back to the computer by linking Kinect to Qyokka plug-in in grasshopper. The designer will show a component to Kinect. Being recognized by Kinect and calculated by computer, the generative outcomes will be shown on the ongoing material surface through the projector (Figure 3). The result will be influenced

by the component location which placed by the designer in real-time. The physical information will transform into virtual information digitally through this method.

To transform the 3D virtual information to material, a color-based information projector system was designed. Kinect will detect the distance between the physical model and sensor, and the color will be projected to the physical model surface from blue to orange. Blue indicates that it needs to move in the horizontal direction. The closer to orange, the closer physical model is similar to the digital target in computer. The builder just needs to heat-bent the material under the guidance of the color shown on the surface. When the full color changes to orange, the physical fabrication process is complete (Figure 4). By transforming the distance information detected by the Kinect sensor to the augmented color information projected by the projector, designer and unskilled labour can fabricate the material manually by the color guidance shown on the model.

Although the result of this test is quite success-

ful, it has a massive limitation through this Kinect and projector system. Because the projector can only provide 2D information the builder can only fabricate in one direction. If we use multi-Kinect and multi-projector system to provide 3D information, this will cause unnecessary errors inevitably. The best solution is to find an AR device and method to offer a 3D holographic fabrication introduction instead of using a projector to improve the accuracy of physical outcomes.

BloomShell Experiment 2
- custom-made system
The fabrication process of heat-bent cannot be controlled precisely because of the information transmission errors between Microsoft Kinect and a projector. The projector can only show 2D information. Therefore, 3D space geometry such as double-curved surface cannot be achieved under the 2D information guidance. In this research, we change the device from Kinect and projector to Microsoft HoloLens. The Microsoft HoloLens was invented to show 3D holographic and animation overlaying in the real world, which has the capability to illustrate 3D fabrication guidance. Microsoft HoloLens enables the user to engage with digital content and interact with hologram in the real world.

Figure 3
The Kinect device identify system and the projector showing system about the human interpretative generation outcomes in real time

Figure 4
The color-based augmented fabrication guidance information through Kinect and projector system during modeling process

Figure 5
The BloomShell fabrication guidance interface in Augmented Reality including the process guidance, video illustration, material information, etc.

Figure 6
The Augmented Reality hologram guidance in component deform area from HoloLens
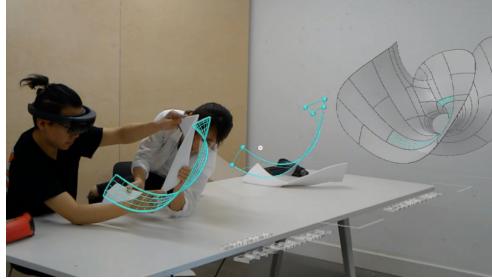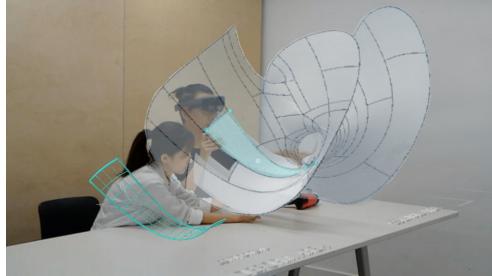
Figure 7
The Augmented Reality hologram guidance in assembly area from HoloLens

BloomShell experiment 2 (custom-made system) explores continuous double-curved surfaces assembled by custom-made components which can be produced efficiently in AR for unskilled labor. The components are made from synthetic material - polyurethane foam board laminated by two WBA sheets on each side - each component can be bent to any curvature by applying heat. WBA sheets will be sticky and flexible shaping when they reach a certain temperature. Therefore the component can be Heat-Stick panel to panel without additional joint and can be Heat-Bent without prefabricated mould. WBA sheets will be strong enough when they cool down to support the load and weight. The polyurethane foam board in the middle will maintain the suppleness and curvature of the surface and enhance the structural support.

The user can follow the BloomShell interface in HoloLens headset to activate the 3D holographic fabrication guidance step by step. In order to do this, the interface with the selectable buttons (Figure 5) was developed and imported to Unity. To create the corresponding code will help the user visualize each step of the virtual fabrication illustration process in Microsoft HoloLens. The script in Unity allows users to activate the program when they gaze their eye on the button of each option shown on the interface in Microsoft HoloLens by "Tap" gesture.

When the interface is activated, the user will first select the fabrication object and the user will be guided to Heat-Bent each component by the hologram shown in Microsoft HoloLens. For example, after the user selects the chair object, it will show a Component Deform Area which guides the user to Heat-Bent the flat component to fix the 3D hologram (Figure 6); and an Assembly Area which guide the user to Heat-Stick the 3D component to adjust the right hologram position in the real world (Figure 7). All the processes will be identified and guided by Microsoft HoloLens. The user can perform the "Tap" gesture again when he finished the first component, and the second will be shown. The user can Heat-Bent and Heat-Stick the second component indicated by Microsoft HoloLens and repeat the "Tap" gesture step-by-step to finish the whole object fabrication process.

The further development will focus on establishing the output of instructions for physical execution. An "auto labeling system" was established, an AR-based workflow that assists unskilled labor in identifying each of the prefabricated components using computer vision analysis through Microsoft HoloLens.

The unskilled labor first shows the sensor the component which needs to be identified. The computer will detect the outline of the panel and analyze pixel information to identify the component within the overall surface. After being recognized by the sensor, all the necessary information about the component, including label number and precise position within the global surface, will be sent back to the Microsoft HoloLens and shown to the unskilled labor as a hologram overlay to the physic component (Figure 8). This process can help the unskilled labor who is wearing the Microsoft HoloLens AR headset to recognize and find out the corresponding compo-

nent quickly and to fabricate step by step using the "Tap" gesture and finish the fabrication process by the holographic instructions.

It is worth discussing the initial approach, as it required the use of computer vision in order to identify different components and provide unskilled labours with instructions on labeling and positioning of a component on the overall surface through Augmented Reality (Figure 9). The custom-made system has the limitation that it makes the process harder for the computer to identify different components. It is difficult to improve the accuracy of the smooth curve surface by using different sizes and different shapes of custom-made components. For this reason, a shift to a unified component tile system was made. That will provide a higher degree of freedom during the assembly process, as well as compensating for any imprecision and accumulated error during the fabrication process.

BloomShell Experiment 3 - tile component system

BloomShell experiment 3 (tile component system) explores continuous doubly curved surfaces assembled by a single type of component tile which can be modified and simplified easily in AR.

Early BloomShell studies utilize custom-made components in order to describe a given surface. This was later replaced by the tile component system to allow for greater flexibility. The idea of using the same tile component type will make it achievable for the sensor to identify the component and for the designers to interact with the components during the construction process. In addition, the device will scan and identify the key tile which has been changed and modified differently from the digital design by the designer according to their preferences and inspirations during the construction process easier. This system provides a flexibility relationship between human and computer, which allow the designer to obtain different design outcomes from furniture to building elements.

In order to achieve that, we upgraded out AR interface to adapt the tile component system. Designers can choose the object which they want fabricate first, after that, they can select the shape of the tile component such as rectangle or oval, etc. and preview that in the AR device. The detail information of the object will be shown by the holographic instruction in Microsoft HoloLens, including the number of tile component the designer need to prepare, the location of each component and the fabrication time. Designers can also control the construction process by themselves using "Tap" gesture (Figure 10).

The material of the tile component is lightweight, the direction of the component does not influence or change the structural properties of the surface itself, but can bring the various outcomes of the surface instead. The idea of changing tile direction will lead this research into an immersive interactive design, which allows the designer to make changes to the component direction on a local scale while maintaining the whole shape on a global scale

Figure 8
The demonstration of computer vision recognition: recognizing physical panel sillouette and showing label information in AR

Figure 9
The work flow demonstration and fabrication recording of BloomShell test 2 - custom-made system
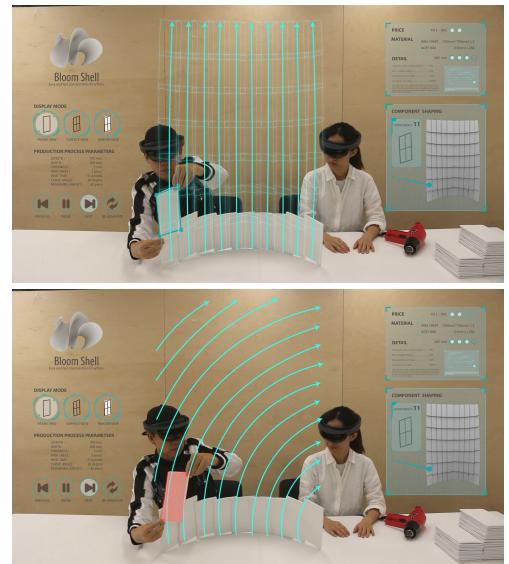
Figure 10
The work flow
demonstration and
fabrication
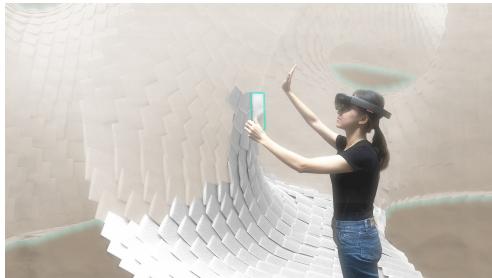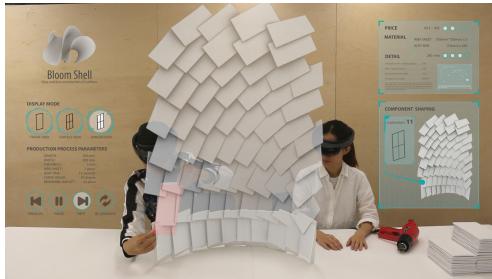recording of
BloomShell test 3 -
tile component
system

Figure 11
The self-standing
wall with basic
panel calculated by
computer before
human-made
change

Figure 12
The self-standing
wall with evolution
scheme calculated
by computer after
human-made
change detected by
Microsoft HoloLens

to give more detailed outcomes. The headset sensor will detect the transformation and send it to design software to generate a new outcome. For example, the designer can activate the interface by "Tap" gesture and choose the favorite object. If the designer decides to build a wall, a self-standing wall with basic panel will be calculated by the computer and shown as a holographic object in Microsoft HoloLens (Figure 11). However, during the assembly process, the designer decides to change the orientation of the next panel (Figure 12), the computer will recalculate and give the evolution scheme of the remaining panels, while keeping the original wall shape (Figure 13). This process can be done repeatably at any time during the assembly process. This idea will build a bridge between human and computer to let the machine learn and give reasonably calculated outcomes at any time human make new decisions. That will be a new Artificial Intelligence exploration through AR technology.

A 1:1 physical prototype pavilion was produced to illustrate the idea (Figure 14), as well as a larger scale architectural proposal, which was designed to show the application on building elements and architecture scale in the future (Figure 15 and 16). Although, the WBA plastic sheet with polyurethane foam boards can be understood as a concept material, the proposed system is adaptable to any sheet material with flexible bending property without the use of moulds, such as metal sheets and so on.

CONCLUSION

The above experiments give an overview of the current state of AR technologies and the potential for the application in the field of building elements and architecture scale design.

Through the three prototype experiments in this paper, AR technology was initially confirmed to have the ability and possibility for guiding unskilled labour on complex structure assembly and fabrication process by step-by-step 3D holographic introduction. These tests are in the prime of the research, which tries to bridge the gap between digital design and physical outcome by designing a workflow which transforms a 2D drawing into 3D construction guidance for the design and unskilled labour through AR.

These research experiments are not really about training unskilled labours or trying to shorten production time, they are explorations of how people might change their mind or decisions can be changed in real-time manner harmoniously using computer-human intelligence. The three experiments are also designed to give emphasis on the concept of communication between computer and human during the making process through the physical making process. Using an AR device, the computer can detect and identify the designers' thinking and idea at any time, and give reasonable outcomes calculated by fixed rules through AR hologram overlapping on the real world in real time.

Although the last part of experiment 3, computer-suggested solution after identifying a human-made change in real-time, in this paper has not technically achieved yet, the value is to pave the way for complex curved structure projects in the future through computer-human intelligence and AR.

In conclusion, AR accuracy, with step-by-step holographic instructions, can be used for precise and quick execution in manual fabrication, especially for complex curved structures based on a large number of components. The augmented assembly provides the constant feedback loop between the digital and physical to the assembly phases. At the same time, AR provides a real-time scanning capability. It brings

Figure 13
Demonstration of computer-suggested pattern changing direction after recognizing human-made changes

Figure 14
The 1:1 physical model BloomShell Pavilion on B-Pro show of RC9 in the Bartlett school of architecture UCL

Figure 15
The AR holographic construction process in architectural purposes (intended work in the future)

the possibility to interact with AR and get the enormous advantage of feedback through AI to designers in real-time.

Further work will take in premeditation the additional development of real time communication between human and computer interaction through the physical to the digital. This will be done by collaboration not only with AR technology but also AI, Robotics, Wearable Machines, etc., in order to achieve the precise and fast fabrication and assembly of complex structures. The final goal is to make the whole AR-based fabrication and assembly workflow simplified and modified for architectural scale elements and applications.

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Figure 17
BloomShell large scale architectural application imafination (intended work in the future)