FLOWMORPH

Exploring the human-material interaction in digitally augmented craftsmanship

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Abstract. It has been proposed that, after the internet age, we are now entering a new era of the "Augmented Age" (King, 2016). Physician Michio Kaku imagined the future of architects will be relying heavily on Augmented Reality technology (Kaku, 2015). Augmented reality technology is not a new technology and has been evolving rapidly. In the last three years, the technology has been applied in mainstream consumer devices (Coppens, 2017). This opened up possibilities in every aspect of our daily lives and it is expected that this will have a great impact on every field of consumer’s technology in near future, including design and fabrication. What is the future of design and making? What kind of new digital fabrication paradigm will emerge from inevitable technological development? What kind of impact will this have on the built environment and industry? FlowMorph is a research project developed in the Bartlett School of Architecture, B-Pro AD with the collaboration of the authors and students as a 12 month MArch programme, we developed a unique design project trying to answer these questions which will be introduced in this paper.


1. Background: The Augmentation Age

It has been proposed that, after the internet age, we are now entering a new era of the "Augmented Age" (King, 2016). Human-computer interaction is becoming personal and machines are getting close to our body. Humans are no longer limited by their physicality. Our memories are extended to an unlimited amount of information on the internet through the use of smartphones. The word - Augmented - is a broad term including a larger aspect of extended human ability.
through the use of machines. However, a very typical example of "Augmentation" indeed is the Augmented Reality technology. Physician Michio Kaku imagined the future of architects will be relying heavily on Augmented Reality technology (Kaku, 2015). Augmented reality technology is not a new technology. However, in the last three years, the technology became mainstream consumer devices (Coppens, 2017). This opened up possibilities in every aspect of our daily lives and it is expected that this will have a great impact of every field in near future, including design and fabrication. Previous research and commercial applications have progressed this paradigm (Fologram, 2018) and it looks into developing technology to ease the working pipeline for AR based fabrication. It is expected that there will be an exponential growth on creative businesses and this raises questions of our role as designers and architects in the future.

FlowMorph is a research project developed in Bartlett School of Architecture, B-Pro AD as a 12 month MArch programme. We developed a unique design project trying to answer these questions. We departed and elaborate on the idea of Mixed Reality (MR) Assisted Manufacturing (MRM) for highly complex geometry which can neither be effectively managed manually by the fabricator nor by simple conventional robotic fabrication (Brugnaro and Hanna, 2017), proposed an MR+Simulation workflow using a CFD solver. The proposed fabrication process explore a specific material- Polycaprolactone (Polymorph)- researching and developing a combination of specific digital simulation methods to assist the exploration of the material in question in the production of an eventual artifact. By heating and re-shaping (stretching) the plastic, we explore organic structures we called 'Skeleton' and 'Tentacle, being also observant on the vocabulary used to describe objects and methods in this process. The CFD application explores aspects of the human-geometry interaction in the form finding exercise overlaid on the physical reality, taking advantage of cognitive aspects of MR and allowing intuitive exploration of a solution space by ad hoc play with the fluid simulation on the and adjustment of options. This augmentation in the making process affords intuitive exploration in the interlaced making and designing - an enhanced reflection in the design practice. The aim of the research is inspired by the increase in new design tools and practices. 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). The idea of 'material templating' as a key step in the design project demands a closer coupling of a 'make-simulate' feedback system in reflective practice. In this particular project, the plastic used leads to investigate a wide variety of applications of plastic in highly digitalized design. Therefore, we seek a possible taxonomy of random glitches in this workflow. On this paper, we present a survey of the current state of art of MR and CFD assisted manual fabrication, deriving a design exercise and elaborating on the outcomes to propose a road-map for future application of mixed reality in the design-by-making and craftsmanship. On the development of this research, we thank the Bartlett RC9 student Jie Sun and Yu-Hsin Huang for their contribution in the assemblage of models.
2. Material & Craftsmanship

For the last decades, we learned that digital fabrication (such as CNC, 3D printing and robotic) allowed us to achieve better exploration of design variation and innovate in form and functionality. Mass-customization most of the fabrication, works very well with products that needs high precision with little tolerance level. However, most of the digital fabrication processes are usually higher in cost, not able to deal with high tolerance nor be able to deal with highly intuitive on-demand decisions. It is also very difficult to deal with fabrication that requires delicate craftsmanship. In order to complement this problem, we need to re-think about the human-machine relationship. Machines are usually good in dealing with repetitive, heavy, dangerous, precise job while human is good in dealing with delicate crafts, adapt tolerances, making intuitive decisions. During our design research, we tried hard to look for materials and crafting techniques that can be benefit from these aspects of human and machine.

Plastic is low-cost, strong, flexible and elastic in the same time and malleable with craftsmanship. After many tests and trials, we decided to use ‘stretching’ action for the production of physical model (See Figure 1). We used thermoplastic which can melt under certain temperature, and easily modified until it cool down. This technique relies on craftsmanship, allows high tolerance, and free to accumulate in multiple directions. This allows us in great degree of freedom in exploring shapes and geometries. These are some of our earlier prototypes (See Figure 1).

2.1. LEARNING FROM DIGITAL FABRICATION

The human factor in crafting was one of the main topics for the research. The conjunction of human intuition and material behaviour was paramount for the development of the manufacturing technique. Departing from this idea, we used plastics due to its special relation with digital fabrication and the diversity for human interaction with this material. There are many precedents and history of research about plastic 3D printing or robotic spacial printing such as AI build (2018) (See Figure 2) or Branch Technology (2018). Robotic 3D printings are already a leap from traditional 3D printing as it is trying to deal with the behaviour of plastic as plastic is good in tension and stretching rather than accumulation. However, robotic stretching normally requires expensive computing, relying on highly precise calculation of continuous tool path and control of temperature during printing. Our chosen method can overcome these issues and problems naturally by being able to freely form the plastics to any directions from any...
difficult position. There is no need for heavy computing for study of tool path. On top of this, it can freely change size and length of the stretched segments and allows to adopt intuitive changes and adjustments anytime, before, during or after the fabrication process. As contrasted with the highly robotic fabrication process, many of analogue mistakes or failures were acceptable thanks to adaptivity of the process.

Figure 2. AI build.

3. Generative Computation

In order to maximize the synergy of the collaboration between human and machine, we introduced the idea of generative computation to let computer to help us design and make decisions in shapes and geometries in an interactive way.

3.1. AN OVERVIEW OF DESIGN COMPUTATION

Besides the accelerating progress in computational design, to operate computational design tools is a highly demanding cognitive effort. Parametric modeling is becoming exponentially complex. Originally starting from CAD modeling and evolving from hand drawings, CAD modeling allowed designers to realize designs of unprecedented complexity. Following the development of polygon modeling allowed designers to sculpt interact within a digital environment, however, the product is still highly human decision dominated design. Following this is a development of object-oriented scripting, technology allows designs to be generated by sets of rules that are set out by a human. This state is called - generative design - which is still demanding on human-made commands but the resulting products are generative non-manual (Conti, 2017). Introduction of generative computation allows us to maximize the role of the computer, give us creative potentials that allow us to design structures that human cannot imagine nor can manually design.

3.2. METHOD

3.2.1. Jellyfish Simulation

The idea of this simulation comes from the flexibility of the behaviour of materiality of plastic. We have chosen spring particle system as an algorithm of
this simulation, so that a simple geometry can generate quite complex and unique ‘Jellyfish-like’ outcomes. The workflow of this simulation is as follows: we set several structural paths and forces in a boundary box, then let a component move as following the paths and duplicating itself under the physics of the algorithm (See Figure 3).

![Figure 3. Jellyfish simulation.](image)

Structural path exactly represents the direction and rough shape of the outcome. However, we set lock points on the paths to a component so that it is possible to select how many or which points are locked or unlocked. There are several external forces in this simulation such as gravity, wind, speed and bouncing behaviour. We setup a component as simple as possible in order to give us a certain control. Those constraints enable the generative method being executed with a lot of options the simulation therefore outcomes are more varied and unconventional in terms of the geometric uniqueness (See Figure 4).

![Figure 4. Jellyfish simulation outcomes.](image)

### 3.2.2. Fluid Simulation

As a further approach, we went about fluid dynamics to generate more useful simulation outcome. We setup a 3D fluid container with a vector field embedded on it. By adding many forces such as gravity, turbulence, radials and air, the vector field of the fluid engine is also affected. There are several factors that makes this generative process more rich and complex; the resolution of the vector, timing of
the forces, location of the forces and strength of the forces. Those tools enables the outcomes visualized literally because of the forces to the vector field (See Figure 5).

![Figure 5. Fluid simulation.](image)

The outcomes achieved can create very intricate interesting vector field that, we thought might give us very interesting guide for geometries for our structure. In the same line of thinking, as fluid engine work with external forces, it opened up the possibilities for us to think about controlling the generation of shapes through the use of human interaction through gestures using the Augmented Reality devices. As this image shows, the system naturally allows to interact with applied external forces and in this case by using the arms to generate the designing gesture.

### 3.3. GESTURE RECOGNITION

In order to have a deeper insight of interactive design, we have explored several ways of recognizing human gesture. Firstly we started tracking color which can draw a line depending on the movement of a white color component in this case. Also we aimed at finding out how computer can detect our component and suggest the next action. For the component tracking, we set some points, once a component is a allocated to one of the target positions, the grey point changes to green and show other potential positions around it, in red color. When another component is attached to the red points, the process above will repeat again (See Figure 6).

Taking the idea of implementing a more fluid interaction, we gradually developed our gesture recognition into drawing routine performed by the user hands. This method was based in a AR device tracking capabilities, which can detect some specific hand gesture. The curve drawn by hand gesture is directly deployed as 3D mesh in a modeling software (See Figure 6). This system clearly promises the possibility of the interactive design that human gesture can influence a design itself.

![Figure 6. Color tracking, Component tracking and Drawing routine by hand.](image)
3.4. GEOMETRY TRANSLATION

One of the principal aspects that should be kept from the generated vector field is the directionality of the resultant vectors. In order to materialize it as a physical outcome, a geometry logic that can allow us to draw the directionality. Because of the behaviour of our material that it can be stretched with connecting each sphere one by one, some kind of 3D grid that can grow was considered as the more feasible option (See Figure 7).

We studied several types of 3D grid. We have chosen pyramidal grid as our physical geometry which can adjust and deform itself following the directionality. For the overall design, we designed a computing workflow method. Once vector is generated, we convert vector to mesh which has the same topology as the vector field. Then we can deploy the pyramidal grid system depending on the scale and resolution of the topology (See Figure 7). This process can be adopted to any outcomes of vector field we design, and therefore, is able to generate a functional structure.

4. Design proposals & Augmented making

Based on all the studies, we tested our design on furniture scale to test the feasibility. We designed a series of chairs that are directed by the generative workflow process above. The chair catalogue shows the varieties of vector field for the chair design. We picked up one of those, and then applied the pyramidal grid with proper scale and resolution. The finalized chair has a potential of letting us to create an unconventional geometry that is generated by fluid behaviour (See Figure 8). Also as part of the experimentation with the furniture scale, manufacturing was tested and improved through the user experience as a part of the huge interactive potential that the mix of generative design and AR has.
4.1. AUGMENTED MAKING

The actual fabrication process of the corner piece for the BPro end of year show was designed as and fabricated at actual scale (See Figure 10). For the fabrication, the piece is analyzed and designed as previously described. The scale of pyramid grid in this case is calculated from the maximum distance the material can stretch, which is about thirty centimeters.

The AR device for fabrication, is meant to be accessible to every type of maker, so it has to be quite user friendly. As an initial fabrication trial, we tested what kind of information or 3D model are necessary. The trial shows that quite simple hologram that guides a maker is sufficient rather than deploying all of the details of the 3D model (See Figure 9). The small prototype is fabricated only with the hologram of simple lines and points that represent the structure. The process of making is quite simple, and anyone can learn with a guidance. With only the action of stretching between spheres, it is possible to keep the unique design language.

On the basis of those study, we started the fabrication of the final piece. The size is 2.1m height, 1.6m width and 1m depth. The construction was done by three makers in fifty hours. We worked as a team as follows; one or two of us wore AR devices and the other did without it (See Figure 10). The makers with AR device directed the other by pointing out the location of spheres or making basic structure and left the rest of the structure which does not need hologram to construct for the other. It can be said that the fabrication process was quite fast even though some of the makers joined only for the making process on that day. Before starting fabrication, we instructed them in how to use the material and explained the conceptual principles. In other words, this fabrication method is quite universal regardless of the skill of the user. This is one of the most beneficial aspects from the experience of the fabrication. Needless to say, there are some drawbacks that need to be solved. There is a sort of limitation of the distance between makers and the model due to the size of the window of the AR device. If a maker is too close to the object it would be hard to see the hologram, this may limit the convenience. Also, if there are several makers wearing the AR devices, sometimes the location of holograms are a little different depending on the devices.
It can generate a tolerance problem, which in the other hand can be easily solved by the human factor in the manufacturing. Those issues are mostly technical matters, but it took some time to become used to it for the makers. However, the augmented fabrication provides us an intention of new design method and fabrication method.

4.2. ARCHITECTURAL SCALE

FlowMorph, as an architectural project has the potential of not only developing itself in a bigger scale, but also been the benchmark for other building techniques that can explore new paths from the same basic manufacturing process. In terms of developing the proposed method in a greater scale, different paths are worth to be explored. From a material perspective, FlowMorph can explore new composite materials that could follow the same behaviour as the polymorph plastic, keeping the adaptability as a key feature while improving the mechanical performance. Some composites like bio resins or plastic resins are good candidates to research for an architectural scale. The second most interesting area to investigate would be the augmentation of the manufacturing via new devices that combined with the human factor could achieve a more precise and technical result for the physical modification process of the components. Those two factors have the potential of scaling this system into an architectural element such as a façade or internal division element in a traditional architecture sphere. But the actual potential would be the possibility of creating a new language design that would be able to generate architectural structures designed and manufactured by and for the user in a simple and efficient way adapting every building into all the possible needs.

5. Conclusion and Further Research

This research prototyped a digitally augmented craftsmanship experiment and presented participatory observations of state-of-the-art application of MR to assist ‘design by making’. By doing so, it sheds light on new approaches to integrate digital augmentation into the making of artifacts and enhancing cognition models of making. This challenges the traditional role of the artisan, proposing or teasing a more digitally democratized process to all stakeholders involved in design practice. The project also enhances the relation between technology, design and making by proposing a circular workflow instead of the traditional linear
process. From the research approach, making is a tool for removing the barriers between digital design, digital fabrication and handcrafting. Generative design opens the discussion for how design is considered and how architects decide on value and the ‘ideal’ outcome. By utilizing ‘unexpectedness’ in conjunction with materiality, it might be possible to design the unconventional or unseen. The proposed new approach used in the introduced model takes into the account factors and activities that are related to the external environment of designing (design medium), and to the different types and levels of representation. Future work will take into consideration the interaction observed to develop a semantic analysis of the effects, effect, and interference of digital on the physical (Sherman and Strang, 2004). It will aim to run a number of controlled experiments to test variables like type of materials, simulation, and interaction in this making processes (Hou et al., 2013). In this process, we will aim to also develop an ontology of the many behaviors observed (Anderson, 1994). We also envision the expansion of collaborative versions of the experiments and the formulation of collective behavioral models derived from the participatory observations and experiments. Our final goes are to create an inventory of the culture of augmented making, identifying and dimensioning the effect of the many emerging technologies in the critical production of design and in the collective engagement of the designer in reflective practice of making.

References