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Augmented Manufacturing / *Fabricación aumentada*

The evolution of digital technologies and their rapid adoption by our society is shifting traditional paradigms. The normally conservative industry of architecture is now leading the integration of new techniques in multiple ways. Technologies like 3D printing, robotic automation, platform-based apps and Mixed Realities are changing architecture workflows. Using these interfaces, designers and builders are leaving the Post-Industrial Age to enter the Augmented Age.
Looking towards the near future, the use of Mixed Reality technology will change the traditional role of the workforce, enhancing and extending their skills. Future workers will have access to real-time skills and guidance through augmentation, facilitating and preserving traditional craftsmanship and integrating them simultaneously with computational architecture.
This research explores how the application of augmented reality can challenge the concept of the traditional artisan and propose a new approach to the access of skills and labour in manufacturing methodologies for the architectural environment. The analysis will review the impact of mixed realities by studying three study cases themed into two different topics, craftsmanship and digital platforms.

La evolución de las tecnologías digitales y su rápida adopción está cambiando paradigmas tradicionales de la sociedad. La tradicionalmente conservadora industria de la construcción está ahora, en diversas formas, liderando la integración de nuevas técnicas. Tecnologías como la Impresión 3D, la automatización robótica, plataformas digitales o Realidades Mixtas, están cambiando la industria de la arquitectura. Mediante el uso de este tipo de interfaces, diseñadores y constructores están dejando atrás la Era Post-Industrial para entrar en La Era Aumentada.
Si miramos al futuro cercano, el uso de la realidad aumentada puede cambiar los roles tradicionales de los trabajadores, mejorando y extendiendo sus capacidades. Los trabajadores del futuro, tendrán acceso en tiempo real a habilidades y guiado gracias a la realidad aumentada, facilitando así preservar técnicas artesanas tradicionales integrándolas a la vez con arquitectura computacional.
Esta investigación explora como el uso de la realidad aumentada puede desafiar el concepto tradicional del artesano y de esta forma proponer un nuevo enfoque al acceso a capacitaciones de fabricación para trabajadores en el ámbito de la arquitectura. El articulo analizara el impacto de las realidades mixtas mediante el estudio de dos ejemplos diferenciados en tres temáticas, artesanía y plataformas digitales en arquitectura.

Augmented reality, Digital Architecture, Skilled Labour Shortage, Digital Craftsman, Augmented Manufacturing /// Realidad Aumentada, Arquitectura Digital, Escasez de mano de obra cualificada, Artesano digital, Fabricación aumentada

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Introduction

Digital architecture and its progressive inclusion, as part of the mainstream environment, have allowed for a relevant new scenario, where implementing new ideas or approaches in architecture theory is no longer slow nor conservative (Carpo, 2017). Although the research on digital architecture is not new, it started in the 60s (Frazer, 1995), It is possible to see a significant change in design and building techniques in the last decade due to the absorption of technologies like robots or CNC-making from academia to commercial construction (Yuan, 2018). The radical changes have been produced almost entirely in the XXI century. In just over the last decade, we have changed the millennia-old hand drawing technique with a BIM-based logic. Prefabrication through automation has accelerated the technification of architecture, and as a result, we have moved from mass-based construction to parts-based construction (Claypool et al., 2017).

On the other hand, The Skilled Labour Shortage is a new problematic trend which is probably related to this situation (Brucker et al., 2021). The adverse effects of the shortage are even more patent in developing economies where the architecture industry is struggling to progress because it is almost impossible to find the required skilled workers to modernise the construction systems (Auwalu et al., 2018). This scenario is causing a necessary simplification of techniques, affecting the industry in several ways (Hussain, S. 2020).

Modern technologies are critical in improving architectural efficiency (King, B.,2014). To continue to improve the industry, architecture labour, especially building-related labour, should have the resources to up-skill and re-skill themselves. A possible approach to tackle this need could be augmentation technology (Kaku, M. 2014).

What is AR?

Unlike a specific technology, augmented reality is part of a more significant gradient of digital technologies called Mixed Realities (Milgram & Kishino, 1994). This group of technologies allow different interactions between human-machine and reality. Various media can be used to experiment with any level of MR. The only requirement is that the digital device must alter the human's typical understanding of the real world. 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 (Rosenberg, 1997).

AR Evolution

Augmented Reality originated with the invention of the reflector sight in 1900 as the first example of virtual information concerning the real world. This system, thus rudimentary, could project information on transparent see-through glass. This device became more interactive as the early HUD systems (heads-up displays) were developed for the British and American pre-WWII fighter aircraft. Those early devices were just a basic projection of some data into the screen but could not correlate with the actual environment. This ability was invented a few years later with the first interactive HUD developed by the RAF in 1942. This device could target and display potential enemies and locations using the radar, plus projecting a complex artificial horizon to assist the pilot's navigation.

Regarding wearable devices, the evolution is similar. The first interactive augmented reality portable device was the evolution of the HUD, the HMD or Head Mounted Display, developed in 1962 by Hughes Aircraft Company. It consisted of a compact monocular transparent display attached to the pilot helmet and connected to the missile control unit.

This technology remained away from the public, and its uses were not developed in the military field only until many years later. Only in the late 70s was it first introduced into commercial aeronautics, and later in 1988, into the car industry with the Cutlass Supreme car developed by Oldsmobile in the United States.

Although very relevant for the Augmented Reality evolution, those technologies were not fully immersive experiences. Those devices could only showcase information but could not interact with the user. The first technology to offer a fully immersive experience to the user was developed in 1992 by Louis Rosenberg, and was able to provide interaction through controllers connected to the head device making this system the first step into commercial uses for augmented reality. Nevertheless, the most critical change for augmented reality was the mass commercialisation of smartphones, especially from 2008 with the Android G1 Phone. This smartphone uses the primary camera to overlay information into the real world. With this technology, AR jumped into a broader and more commercial audience and became accessible to all users. This factor was very relevant to show the big technological companies the full potential of the technology. A suitable proof was that Microsoft launched the first version of the HoloLenses in 2015, the first commercial-professional-oriented self-contained augmented reality device in the market.

AR in architecture, precedents

The implementation of AR in architecture was on par with the commercial evolution of the technology. Early examples of using different sources of augmented reality have been made in the last 20 years within the research environment. Still, only some have been transcended into a commercial state. The earliest professional application of this technology might be related to the conservation and restoration of heritage buildings. Archeoguide showed the potential for using overlapped digital information in the real world (Vlahakis et al., 2001). We can find a similar approach as the first professional example of commercial applications for AR, Trimble Navigation (2004). This project allowed the potential buyers of a house to explore and interact with the 3D model of the house before construction on site for the first time.

Fig. 01. Archeoguide Visualization. http://citeseerx.ist.psu.edu/

Although not strictly architectural, but based on the urban environment, mobile games like Pokemon Go, introduced the technology to the mainstream public using AR to navigate the city and interact with other human players (Paavilainen et al., 2017). In terms of Augmented spaces, The Medusa exhibition at the V&A in 2021 showcased a completely walkable and animated augmented space that multiple users could experience at the same time. In terms of software, apps like Fologram or Arkii integrate common devices like smartphones to interact with complex AR models in an accessible format (Jahn et al. 2022).

Skills in the Augmented Age

The physicist and futurist Michio Kaku has theorised that soon, humans will collaborate closely with machines in any manufacturing area. Technologies like AR or mechanical augmentation will be standard, and hardware and software will contribute the same creative value as human workers (Kaku, 2014). As a result, access to skilled labour will expand similarly to access to augmentation technology. In that sense, the future of the skills will give access to more workers thus improve their flexibility; it is possible that at one point, manufacturing or construction officials will be more proficient in the use of hardware and software, and therefore any task from forging to carpentry will be of easy access through augmented devices (King, 2017). Although it is possible to theorise that this shift can have negative socio-economic consequences, this paper will focus more on the positive aspect and how this technology can help standardise access to skilled labour no matter where you are based.

Skilled Labour and Scarcity

Mason guilds are probably the earliest form of labour association and the first system of skills qualification in the building environment. They defined every worker's task and classified them by level of skills and proficiency, granting them the corresponding grade of gratification for their work. Although more diverse and technical, the current system and the different officials and engineers still comply with a similar method to classify the varied works in an architectural project. One of the main reasons this system is still similar is because it is still based on a linear learning method where the worker specialises in a set of particular skills that are perfectioned with time. That means a worker cannot become an expert in a skill without actual working experience. This fact has narrowed the

Fig. 02. Digital Guidance for the Toca Pavillion. http://obuchi-lab.blogspot.com/2015/11/toca-pavilion-work-in-progress.html

access to people to specific knowledge mainly because some of the more specialised skills are no longer that common due to industrialisation and prefabrication. Another relevant factor for the disappearance of the technical workforce is related to the shift in the economic trend. There is now a noticeable growth in intangible investment, and a significant portion of the younger labour is moving towards this direction. This last situation affects not only the specialised workers but secondary sector workers in general, making manufacturing roles less attractive for the younger generations (Hussain et al., 2020). Although those two factors are not the only ones in play, they are relevant to the current situation.

Construction, especially the most specialised roles like carpenters or formwork makers, is suffering greatly from this access to labour, which is driving the cost of the projects up and creating delays (Abdol et al., 1999). Likewise, because there is a greater need for a skilled workforce, skilled labour from developing economies is now leaving their countries to work in wealthier economies, affecting local communities and their progress (Auwalu et al., 2018). This particular effect is also relevant because it risks halting the development of emerging economies and local areas.

Augmented Skills

The built environment has been using tools since the early dawn of the settled human. The processes of making and measuring devices were widely used in the ancient past and are part of any construction process. Augmentation technology has the potential to enhance a worker's performance, not only by enhancing its cognitive capabilities but also through hardware enhancing its physical capabilities. In that sense, AR can guide and improve the precision of a making task. In fact, Several manufacturing companies have already been implementing different augmentation devices for years. Companies, like Boeing have been researching and using this technology since early 1990 (Regenbrecht et al., 2005). Companies, like Thyssen Krupp, are already using this technology in a controlled industrial warehouse environment and on-site to procure better servicing works

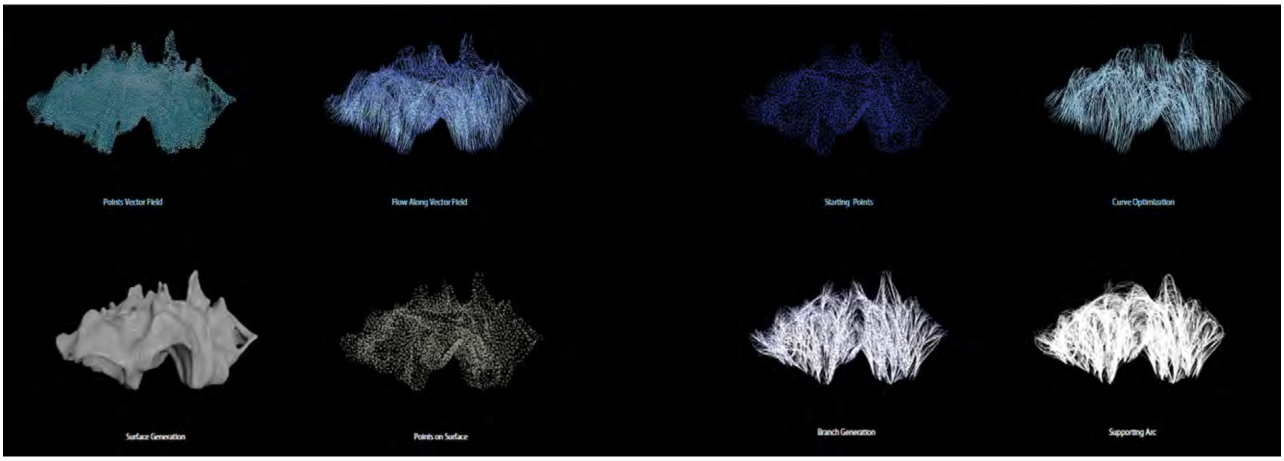

Fig. 03. Particle System. By the MindCraft authors. 2018.

for elevators and escalators (interestingengineering.com). The on-site use of augmented reality devices for skills enhancement is relevant because it proves that AR has a portable factor that can be very important for its implementation in remote or not-developed areas.

Augmented Reality, as a fully interactive technology, can have at least some solution to the problem by helping prospective artisans and officials to learn making processes in a remote distributed way, as well as enhancing skills of the non-skilled workforce in any place where they are needed.

Digital Platforms as Skills Suppliers

Interestingly, it is possible to trace parallelism to the current situation. Since the creation of Mason´s guilds, the knowledge technique for builders has been connected to a platform system. One of the main functions of the gilds was to standardise and spread the expertise in the building and craft arts, even in a very analogous way (Epstein,1995). The problem with this system was that the expansion of the skills was limited; typically, it was under solid surveillance from the guild, narrowing the access to new members and sharing singular techniques with other guilds (Jovinelly & Netelkos, 2006). The transmission of knowledge was scarce, and through a slow apprentice process prioritising the use of skilled workers towards relevant buildings of the time like cathedrals or palaces. However, expanding building knowledge is not the problem but the society that discourages training skilled construction workers. If there is no proper motivation for the workforce to be trained, the process of training them is posed to disappear naturally.

Although remote teaching has existed for decades, the big revolution started with mass media. Since the creation of the internet, digital platforms have appeared to gather people with similar interests. From the first forums, knowledge has been transmitted from user to user in a direct way. One example of this new skill-spreading form is the video platform YouTube. Millions of video tutorials about making can be found in almost any possible language and for every technique. Online teaching has proven efficient, especially in expanding knowledge in restricted or scarce areas, helping to develop people in disfavoured areas (Nguyen, 2015). Digital platforms can be an exciting asset to expand access to training specialised skills and help close the gap in several areas of building expertise.

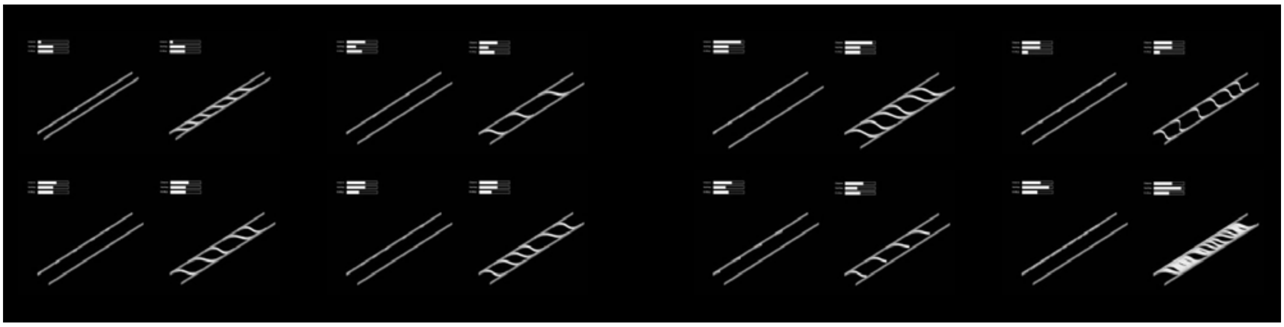

Fig. 04. Computational Joinery. By the MindCraft authors. 2018.

Augmented Manufacturing in Architecture

Guidance elements for construction processes are not new in the building arts. The use of thread lines, spikes, scaffolding formworks, and any tool to connect the plans with reality and guide the process is of everyday use (Ching, 1995). These rigging elements were often complex and challenging to use, as well as heavily wasteful, like formworks or scaffoldings. Digital technologies like Lidars, Lasers, 3D scanning, and robots are now trying to optimise this problem (Papadonikolaki et al., 2020). In terms of guidance and making, Augmented Reality is one of the main actors that can change the traditional approach to making in architecture.

Intro and base reference

Digital approaches in architecture have brought back designs based on complexity and high resolution (Carpo, 2004). This design approach has challenged post-industrial making by experimenting with no replicable elements. Digital manufacturing has overcome this need by implementing CNC fabrication processes that have allowed for a mass customisation logic complying with the requirements of digital architecture (Sanchez, 2018). Even though computer-aided and automation have mitigated to an extent the problem of manufacturing thousands of unique parts for a building, many traditional crafting techniques cannot be achieved entirely through these processes. Arts like forging, steam bending, or clay manufacturing are constraints due to the complexity of those processes (Hahm et al., 2019). To fill the gap between these traditional techniques and digital design, there has been a hybrid approach focused on Augmented Manufacturing.

Early Research Agendas like the one from the Obuchi Lab at Tokyo University show the potential to combine manual manufacturing and human intuition with digital design by augmenting manufacturing guidance using visual projections and computer vision. Through holographic or projection guidance and skills in digitalising, augmented manufacturing can provide the aid needed to manufacture complex, unique parts using traditional making arts. A fascinating example of this methodology is the Toca Pavilion (2014) which used a digitalised archive of choreographies to fabricate a parametrised research pavilion. This example settles the idea of human-machine collaboration as an alternative, more flexible method of computer-aided manufacturing. Another interesting project, the Steam Punk Pavillion developed for the Tallinn Biennale, shows how AR can be used for traditional manufacturing methods like steam bending (Jahn et al. 2022).

MindCraft Project

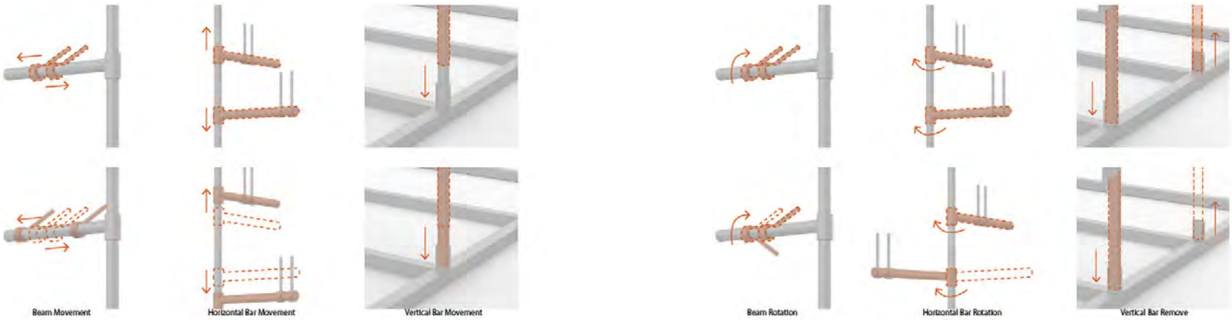

Fig. 05. Frame Digitalization. By the MindCraft authors. 2018.

Wood is one of the oldest materials used in architecture. The techniques applied to its manufacturing have barely changed during the last centuries. Regarding the possibilities of complexity that wood offers, the way to deal with this has traditionally been through subtractive methods like carving. Although capable of reaching a high degree of intricacy, this approach is proven inefficient since it wastes much material and requires a high level of skill from the manufacturer. Such an approach is exemplified in the project of Tverrfjellhytta Pavilion by Shohetta (2011), which shows this idiosyncrasy clearly. It proposes a “computational architecture” made out of wood, manufactured through an “automated” process that increases the waste and requires a qualified production team. Provoking this traditional concept of architecture, Mind-Craft explores how this can be challenged based on augmented reality.

Focused on woodwork as a craft technique, MindCraft proposed a very innovative view of traditional wood steam bending and how to implement the digital design. For this purpose, a digital strategy was generated, from the computational design to the actual crafting, binding together concepts such as material behaviour, joinery generation and emerging manufacturing.

Design integration

The computational approach for MindCraft was also based on the interactivity between the designer and computational logic through augmentation. This new proposal enhances the part of the designer that can now participate in the whole system, which establishes an innovative approach to architecture. With complete integration of the design, manufacturing, and assembly using augmentation, the traditional architectural roles are provoked by eliminating highly skilled crafters from the manufacturing process, allowing unskilled labour to develop the making.

Initially, this project focused on the free interpretation of human gestures for the design process. So, in terms of general design computation, the user would directly interact with the tracking system from the holographic goggles to generate the base guidance for the computational design. The gesture recognition, in this case, generates some attractors that actively guide the generating “voids”, creating the main lines of the design. For this design stage, a vector field interacts with the attractors and makes the voids flow through it. The primary line generation has a behavioural logic added, in this case, a vortex generation, to implement specific patterns into the design.

Fig. 06. Augmented Manufacturing. By the MindCraft authors. 2018

Once the main lines and vortexes are generated, the interactive system allows editing of the lines after the generation using the AR device and control points edition. This concept is very relevant since it adds a factor of human intelligence into the machine logic of computation.

The second layer for the computational design is based only on generative code, and it implements the material behaviour into the project. Following the main lines, the software generates a series of branches to compose the main structure. For the generation of the branches, the actual geometry of the wood is used together with the bending parameters extracted from the empiric experimentation and scientific data is applied. After this logic, the main family of elements is generated.

The joinery system in this project was defined as an integrated part of the design following similar rules to the main layer, so they are completely integrated. From the technical perspective, the joinery layer was designed with two main purposes, to connect the main branches and, at the same time, to reinforce the overall structure. For its design, some constraints were added to the generative logic. The main constraint was the connection system required, in this case, a tangent connection. This need was based on the idea of a fully wood-made frame. In terms of design, every joinery element was bent to achieve the tangent connection. Another constraint was based on the bending capabilities of the wood. Different strategies were designed to allow the proper bending based on the distance to cover with the joinery element, following the radiuses the wood can take. The generative logic resulted in a set of unique connection elements that reinforced the overall design wholly integrated into the design logic.

The whole generative algorithms were also joined into a free, open-source app available online and free to use. This app, designed as a Grasshopper plugin, enhances access to unskilled people in the design and manufacturing phases of the project. The integrative design process was created to produce an outcome that would comply with the wood's structural behaviours and a simple part-based design accessible for manual assembly.

Augmented manufacturing

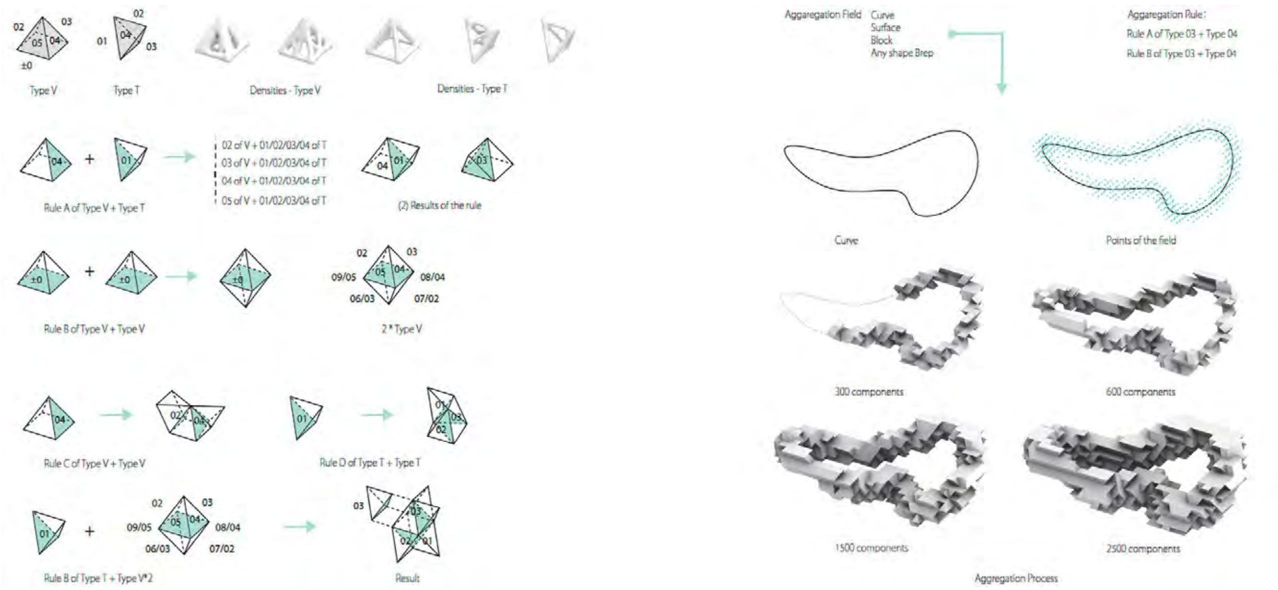

Fig. 07. Computational Generation. By the CeARamics authors. 2019

The manufacturing approach for MindCraft is not far from the previous project but added a new derivate into the process. Unlike the Diffusion project, in this case, the dynamic manufacturing frame was introduced as a part of the augmented performance. Since steam bending requires time to dry and harden the wood once it is formed, creating a flexible and interactive frame was a main part of the manufacturing process design. The frame was then constructed using a grid to locate a series of posts according to the model's needs. Also, within the posts, a series of orientable clamps can be positioned to fix the steamed wood in places to be hardened. The whole frame was then digitalised and implemented into the augmented manufacturing process.

Positioning, bending and twisting actions were visualised in the AR device and guided by a specific sequence. This guidance also included the adjustment of the position of the frame elements as well as the addition, if required, of new bars and clamps. The making of the steamed parts was then achieved through the use of AR projections over the digitalised frame. To increase efficiency, the frame was designed to form individual parts isolated or bigger chunks of several steamed parts. That would mean that the augmented guidance would allow for a form & assemble process that could allow for even complex parts that were impossible to construct with hardened pieces.

This augmented logic allowed the students with no previous experience in wood steaming or wood making to produce a complex and intricate prototype thoroughly skilled by the Augmented Reality Device.

Augmented Assembly

Although assembly was not the focus of the MindCraft project, the complexity of the prefabricated components required AR guidance to help assemble the final model. Due to the size limitation, efficiency, and material constraints, the final model had to be divided into several smaller sections that could be fabricated individually within the frame capabilities. The result was a series of complex assemblies for this section that required an exact connection of border elements and the addition of connective

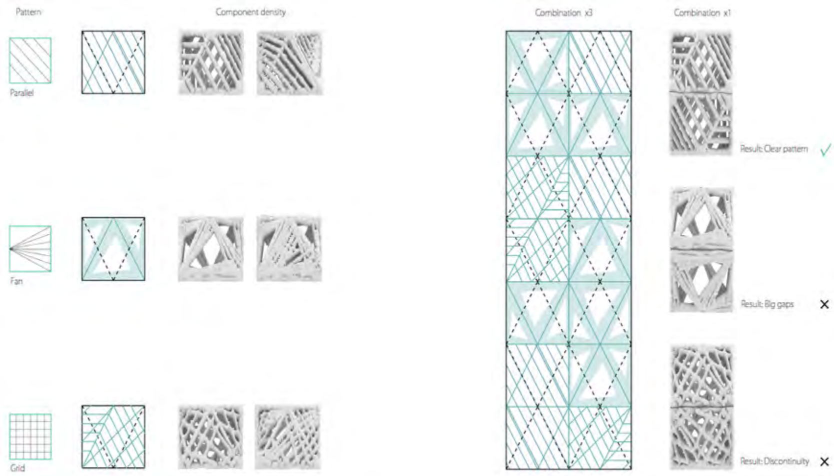

Fig. 08. Pattern Density. By the CeARamics authors. 2019.

elements to assure the stability of the model. To ensure the final assembly was correctly processed. Since the intricacy of the parts was deemed inefficient to create or follow traditional plans, an Augmented Guided assembly was also used to construct the prototype.

The combination of making and assembly, even for big models within the same app, shows the potential and flexibility of these techniques to promote instant skills to workers through augmentation technology. In this project, the same individuals conducted the whole development of the project, from the digital design to the final on-site assembly adapting their role in the project with the assistance of technology.

The CeARamics project

Vernacular materials are essential to the study of the potential for Augmented Reality to supply broader access to a more advanced and optimised technique in the construction environment. Clay, in that sense, represents a paradigmatic material used since the early dawn of human architecture (Weston, 2003). In recent years, several projects have explored the possibilities of automated manufacturing processes for clay, such as 3D printing. Those processes, although somehow efficient, require advanced knowledge of the technology and complex machinery. These requirements limit its expansion, which can reduce access to remote or undeveloped communities.

The CeARamics project then explores how it is possible to create a distributed manufacturing system for clay components in a “Gig-economy” based context through AR manufacturing and platforms. Based on the idea of human crafting, this project uses a ubiquitous technology like a Smartphone to produce highly detailed clay components with the guidance of AR over imposed instructions. That allows unskilled workers to participate in the process quickly and widely. From this perspective, the use of clay for complex and optimised components has become accessible to even more communities which is especially relevant since clay is widely available throughout the globe.

Design Integration

Since this project aims to achieve a local clay manufacturing system, the computational design approach is based on discrete object logic. In the same way, to case-proof the concept, the architectural tests’ scope is

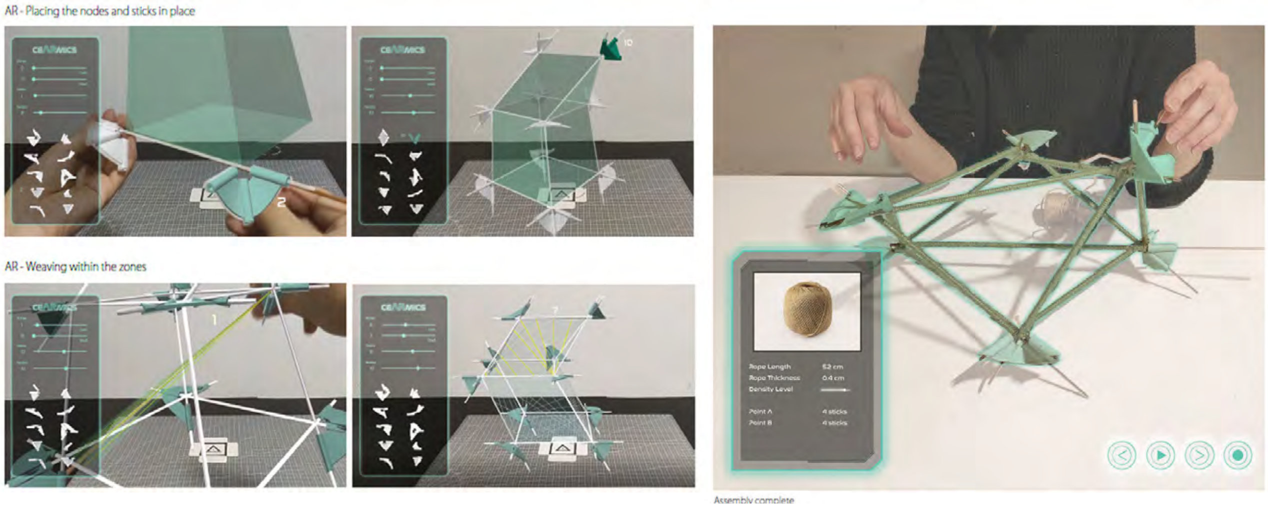

Fig. 09. Augmented Manufacturing from the Platform. By the CeARamics authors. 2019.

focused on a façade system composed of a series of predefined Lego-like parts. Using a simple octahedron as the base geometry, a series of sixteen parts is generated for the main catalogue. These parts are then designed to contain specific patterns unique to each part and controlled by an optimisation algorithm that analyses the isolation patterns and the privacy needs for the façade. A second algorithm is used to organise the parts into the required geometry.

The design logic then starts by imputing the façade in the form of volume into the generative app; this volume is therefore analysed and computed to calculate the part allocation. This process optimises and decides which and how many parts are necessary to fill the volume and obtain a steady assembly. The user can constantly regenerate or adjust the result. The adjustment of the porosity for the parts is also possible to control by adding void exclusion volumes. The algorithm that runs the population of the parts within the volume is based on procedural aggregatory logic. As a result, the app will develop a wall assembly outcome that will catalogue the parts used and work as the base for the pattern application step.

The second layer of the computational design logic is the pattern design algorithm. Once a section of a wall or façade is computed and approved, the light and privacy optimisation sequence starts. Every part has a predefined logic for the pattern based on manufacturing constraints; this way, the logic can easily assign density and direction for the pattern for the visible faces. In combination with this, there is also a predefine universal logic to fill the faces that are not visible and therefore have a more structural purpose. After the density calculation, other parameters like privacy are added and combined to generate the final design result.

A good advantage towards component generation and pattern consistency in manufacturing is that the design is generated per part and then combined instead of having a general approach and then subdividing it.

That is possible since the algorithm uses a vector-based neighbouring system that creates a continuous aesthetic through discrete logic. That also

Fig. 10. Manufacturing process. By the CeARamics authors. 2019.

ensures that every part can be easily classified and catalogued into the system for manufacturing.

Augmented Manufacturing

The production of complex three-dimensional components in clay was the main target for Augmented Manufacturing. Considering the idea of unskilled makers and allowing for broader platform use, the system designed for the process was simplified to allow for easy access. That meant a simple kit that could be delivered to every user consistently in a series of sticks and joineries to construct the temporary frame for the hemp thread weaving. Therefore, the first step for manufacturing would be assembling the frame using the AR guidance following step-by-step instructions. Once the frame was assembled, then the weaving process could start. For the weaving, direction and guidance for every face were given so the maker could comply with the pattern requirements. An unrolled version of the polygon for the weaving part was also provided with guidance to facilitate the reading. The process would follow a specific optimised order for the faces. The Augmented Reality App could also check every face to confirm its accuracy. After completion, the whole component could also be checked and saved as completed. One interesting proposal was the possibility of recording the weaving process and saving it to share with another user to allow for a more consistent result among different users.

After the weaving process, the clay is applied by dipping and set to air-dry, and once it becomes hard, the temporary frame can be removed and reused for the next component. For the glazing and cooking process, the components could be sprayed or dipped into the glazing paint and then traditionally cooked in the kiln. The hemp-based rope used as scaffolding for the weaving will burn into ashes without effect on the clay, avoiding cracks or noxious gasses during the kiln cooking.

Augmented Assembly

Once the components were produced, the proposal for the app was that they could be collected and delivered to the building site. Since every component is unique, a computer vision system could recognise them and provide them with the information needed for the final assembly. A series of clusters would be pre-assembled for the actual assembly using AR to secure them into the structural framework. Once a cluster is completed and checked with Computer Vision, it could be craned using the structural frame and assembled to its façade final position.

Conclusions and Results

the inclusion of disruptive technologies in architecture has always created controversy in a traditionally conservative industry (Carpo, 2014). The use of Augmented reality in architecture will probably not be different. Although some built projects have been completed (Pantic, 2019), much more development will be needed to fully integrate it into the mainstream construction industry, as the technology is still in its early years.
If we analyse the study cases presented here, there is a strong potential that Augmented manufacturing could at least bring back the craftmanship renaissance into architecture. As shown by the MindCraft Project, the possibility of digitalisation of crafting methods like steam bending is possible and allows for a very modern computational design system. Through the use of augmented guidance, we can produce not only intricate crafts but also merge digital design with traditional making techniques. Another exciting idea is the possibility of including the "Gig-Economy" in the future of architecture through platforms and Augmented manufacturing. This concept could allow a more diverse distributed manufacturing, opening the building industry to a broader workforce pool.

Also, in this direction, the CeARamics project shows the potential for a new form of prefabrication using traditional materials in innovative, accessible manners.

However, probably the most relevant conclusion it could be extracted from the study cases is that with the use of augmented reality, there is a real case for allowing more unskilled labour to access more complex construction techniques instantly.

The proof of this potential was that students without previous manufacturing experience built both projects and produced very complex and successful prototypes. It is logical to think that in the "real world", there will not be a need for such an intricate design. Nevertheless, the fact that those are achievable through augmented guidance indicates that more straightforward tasks can be performed by using this technology.

The problem of the Skilled Labour Shortage will probably not be solved with just one solution but with a combination of several ideas. What is clear is that technology will be an essential character in helping to solve it. Better efficiency, local materials, optimised processes, and improved design or prefabrication will be areas that architecture will need to look to improve the construction industry necessarily. Many of these factors can be improved through distributed manufacturing and augmented technologies, so it will be essential to continue developing these technologies for a better and more inclusive architecture in the future.

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