Code-Bothy: Mixed Reality and Craft Sustainability

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Abstract

Code-Bothy examines traditional bricklaying using mixed reality technology. Digital design demands a re-examination of how we make. The digital and the manual should not be considered as autonomous but as part of something more reciprocal. One can engage with digital modelling software or can reject all digital tools and make and design by hand, but can we work in between? In the context of mixed-reality fabrication, the real and virtual worlds come together to create a hybrid environment where physical and digital objects are visualised simultaneously and interact with one another in real time. Hybridity of the two is compelling because the digital is often perceived as the future/emergent and the manual as the past/obsolescent. The practice of being digital and manual is on the one hand procedural and systematic, on the other textural and indexical. Working digitally and manually is about exploring areas in design and making: manual production and digital input can work together to allow for the conservation of crafts, while digital fabrication can be advanced with the help of manual craftsmanship.

Keywords

Digital Design; Mixed Reality Fabrication; Digital Craft; Digital Bricklaying; Digital Manual

1. Introduction

Figure 01: Bothy at Grymsdyke Farm

What is a ‘Bothy’? For a recreation hill walker, the Bothy is an unlocked shelter for rest, a cover from the elements, a place to spend the night or a meeting point with other walkers. The one thing particular about the Bothy is that it is free of charge, but one is expected to observe the so called ‘Bothy-Code’. The code is set out based of the idea of respect, urging users to care for the structure itself, limit the number of inhabitants, look out for other users, comply with the landowner’s agreement and lastly to be mindful of the surrounding environment. These unique structures are dotted around the rural countryside of Scotland, originally built for agriculture workers. The economic downturn after the second world war and shifts in rural economy rendered these small buildings obsolete and left uninhabited. The periodic reprieve of their obsolescence is a result of generosity of the owners and the users’ observance of the rules. A building will fall into disrepair without use, and yet its original purpose cannot be revived. The symbiotic relationship between the walkers and a Bothy forms a core principle of environmental and cultural sustainability: opening doors to proactive design of infrastructures and a creative outlook necessary for effective change.

Code-Bothy is a project about the collaborative nature of digital and manual crafts (figure 01). Digital designs demand re-examination of how we make. The development of how we make relies on sustainability of manual crafts. The focus of this research from the onset was to evaluate hybridisation of the real and the virtual worlds. In practical terms, within this hybrid environment, physical and digital objects can be visualised together and interact with one another in real time. The Bothy was designed using parametric modelling tools. The result is a brick structure that can be challenging if not impossible, even for a skilled bricklayer to set-out and build. For the purpose of this project we explored partially digital and partially manual processes. The idea is to equip bricklayers with mixed reality eyewear, a wearable technology allowing them to combine traditional skills with digital placement capabilities so as to build the computational design. The word code in the project title comprises both written laws for the use of a Bothy and computer language for its design and fabrication.

2. Making and Practice

Working together, Piercy&Company and Material Architecture Lab (MAL) at UCL set up a pilot research programme called Making and Practice.[1] The idea is pairing of an established architects’ practice with a material and fabrication-based research programme to design and realise a structure at one to one. As a collaborative platform, our interests in material are mediated through not only experimentation with the current advancement in computation design and digital fabrication, but also via applicability-testing in the construction industry utilising live projects. Our design research aims at methodologies prioritising hybridisation of fabrication techniques, favouring customized systems, designing processes as well as products, digitally controlled machining and semi-automated processes.

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[1] Development of material science also goes hand in hand with technological shifts. Piercy&Company’s architecture emerges out of consideration for the historic, environmental, cultural and economic. As such Code Bothy provided a prime opportunity for exploring how technology and craft could interact in meaningful ways, contributing to continuously evolving cities where profit may take prescience over heritage. Material Architecture Lab’s research method of inquiry is hands-on, set firmly in the realms of empirical testing at an architectural scale. Studio teaching and design projects alike, MAL prioritises making, allowing characteristics of material and fabrication techniques to inform the outcome.

Figure 02: The Bothy is oriented with the entrance facing the south at Grymsdyke Farm

Working digitally and manually provides unique opportunities for the conservation of traditional crafts whilst simultaneously leveraging new technologies to elevate them beyond the restrictions of conventional manual processes. This hybridisation is compelling because whatever the digital future holds, whenever the ubiquity of automation looms, one cannot help but suspect that the human element of design, and in particular architecture, will not completely disappear (Pedro Sousa et al. 2015). There will always exist the potential for design that embraces augmentation or chooses to abstain from it. The questions underpinning this research revolve around digital and manual crafts, hand-made and machine-made. The practice of being digital and manual on the one hand is procedural and systematic, but on the other textural and indexical. There was quite extensive testing in the studio in model form. The overall early concept for the form was manual in terms of combining the practical requirements with orientation north south (figure 02). The north face is protected and the south aspect allows the sun to penetrate into the volume through the oculus for the longest period (figure 03). Code Bothy emphasises that the form was also a manual to digital story and not automatically generated by setting a series of parameters, the nature of it was determined in sketch form and models. The overall design of the Bothy is governed by physical parameters, in relation to sun path (orientation), structural limitations of a free-standing brick enclosure (size and positions of openings) and surface pattern (size of individual bricks). Iterations of design here as such are not generative digitally but embedded through built references like dome and shell constructions. Parametric tools like Grasshopper are overlaid on the overall design to add a layer of complexity to test the mixed-reality collaborative brick laying process. The placement and mortar application for the Bothy have significant consequences for the overall structure, the layers of bricks need to complete each loop to achieve the correct 3-dimensional inclination in order to perform structurally. Simply knowing that it is possible or how best to apply mortar to assemble the brick is not enough. The physical tests of placing bricks and applying mortar is not only an iterative process but also a question of practice. Practice in the sense of training or honing a new skill set that a traditionally skilled brick layer isn't accustomed to. Skills to adapt to this particular construction process cannot be rectified by changing the design or brick pattern, iteration in craft is often doing the same thing over and over again. Through practicing, the intersection between the manual making process and the digital design iterations is a form of optimum outcome.

Figure 03: The oculus is designed for the longest period of sun into the Bothy

3. Brick by Brick

Brick laying is a physically demanding task involving technical skills and familiarity with the material that holds the bricks together, the mortar. Brick's bonding agent, the mortar, often a lime-based material, is the key component for the overall assembly of brick structures. Clay bricks are made to be modular and interchangeable, but they are not identical. Brick by brick, layer by layer, it is the bricklayer's experienced input that absorbs the small differences and judges the tolerances. Eladio Dieste's expressive brick structures are, as a result of not only his clever design and engineering, but also more importantly the construction on one site by his trusted team of masons and brick layers (figure 04). Vittorio Vergalito for example spent more than 38 years constructing a series of reinforced masonry building for Dieste and the architect Alberto Castro (Dieste, 2004). This working relationship between the engineer, the architect, and the craftsman produced some of the most admired and innovative brick architecture of the late 20th century. Expressions in Dieste's architecture are not just applied to the building: they are integrated within the very fabric of its construction. Every brick is placed in a unique and precise way to achieve the overall geometrical and structural performance.

Figure 04: Eladio Dieste's undulating Cristo Obrero Church under construction, © Universo Céramico (https://arquitecturaviva.com/articles/eladio-dieste-100-years)

Figure 05: The Bothy's design with bricks is an exploration of their arrangements

4. Parametric Design, Prototyping and AR

The Bothy is designed with standard bricks in mind using traditional brick laying techniques. In addition, the assembly avoids cutting of bricks and the need for extensive falsework onsite. One of the design aims is to find new arrangements of bricks that form new languages for bricks, to showcase the design achievable in a mixed reality environment. Is the Bothy sculpted with codes? The design of the Bothy is parametrically rather than computationally designed. Parametric design is more the sculpting of constraints and programming of relationships (Asanowicz, 2017). This is an iterative process to optimise the overall design geometry for a set of relational sequences for all the bricks. In other words, the bricks are 'instructed' to follow a given geometry and added geometrical relationship as constraints. Each brick must overlap with all the neighbouring bricks at least by 50%. Each brick in the Bothy is set at a unique angle to itself and with each other: there is no repetition. The rotation of the bricks is parametrically differentiated with code, to allow for the overall sculpting of the form. At the bottommost layer, the bricks are set at 45 degrees to one another. That geometrical relationship gradually and parametrically becomes parallel to one another at the top. The idea is to explore non-standard arrangement of bricks with standard bricks.

Figure 06: David Hussey the chief bricklayer using the HoloLens

Figure 07: The bricklayer with the HoloLens is in constant dialogue with the team

There is a large workforce vulnerable to changes in our construction and manufacturing industry. Social change is inevitable with technological shifts in production: the question of social sustainability contextualises a desired balance between human and automated workforce. The human-machine relationship in onsite construction demands a wider consideration due to cost implications. Mechanisation has altered the meaning of the term skilled work versus manual work. Prefabrication has redistributed the demand and scope for workers with specific technical ability through training and practice, and as such the inevitable deskilling of workforce. Digitisation of fabrication can similarly reduce onsite building work for physical labour, but our research highlights the value of a working together of the digital and manual. Augmenting digital design with skilled workmanship or sustaining existing building crafts through numeric input is a critical area of research. Ensuring that future generations of makers can continue to lay bricks, plasterers can render walls by hand is an issue of sustainability. Human-computer interfaces have increased in the past decades and will continue to rise. This research project acknowledged the social and economic implication of industrial realities, but puts forward essential themes such as craftsmanship, design materiality and decorative art as vital considerations.

The usefulness of augmented reality interfaces in the past had been largely limited to novelty devices, however, research has in numerous fields, from design to mechanical engineering, proven that the tool has more to offer beyond just entertainment (Nee et al. 2012). The technology has improved greatly from earlier systems that made use of video projection mapping to facilitate the placement of materials such as the one described in the paper *Between Manual and Robotic Approaches to Brick Construction in Architecture* where researchers suspended a projector above a platform where they placed foam blocks, the projection serving as a placement guide for the blocks (Pedro Sousa et al. 2015). For the mixed reality interface, we chose Microsoft's wearable headset HoloLens and the software Fologram (figure 07) which marks significant technical leap from earlier more analogue approaches. Looking through the HoloLens is akin to wearing oversized googles and seeing one's surroundings overlaid with a translucent Microsoft desktop. For David Hussey, the chief bricklayer for the project, whose previous work and training had been largely conventional, this addition of the headset was highly novel. As such, using the HoloLens for him was initially cumbersome, founding it 'a little claustrophobic'. However, with time, Hussey began to use it with greater ease, calling it 'quite instinctive and surprisingly straightforward'.

In order to interact with the built-in computer, the wearer needs to look at a particular hand gestures to 'click' and navigate around different menus. When a digital version of the Bothy is loaded and scaled at one to one, a see-through 3D model identical to the one on a computer screen will appear. It is possible to 'move', 'rotate', and even 'walk' around the virtual structure. This transposed digital layer serves as the guide to which the bricklayers will be working (figure 08). It is possible to take a real brick and put it in the place of the virtual one. During actual construction, the bricklayers will 'turn-on' the Bothy each layer of bricks at a time and place the real bricks in place of the virtual ones, one by one. All the key decisions about structure, design and geometry have been taken in the digital model construction. The bricklayer in this mixed reality just needs to focus on positioning the bricks. The space to be taken up by mortar is accounted for simply as a gap between the bricks. In order to fill these gaps, the techniques of skilled bricklayer are indispensable. This messy process calls upon the bricklayer's timing, dexterity and trained movements. One can argue that an onsite mixed reality construction, as such, cannot do without humans.

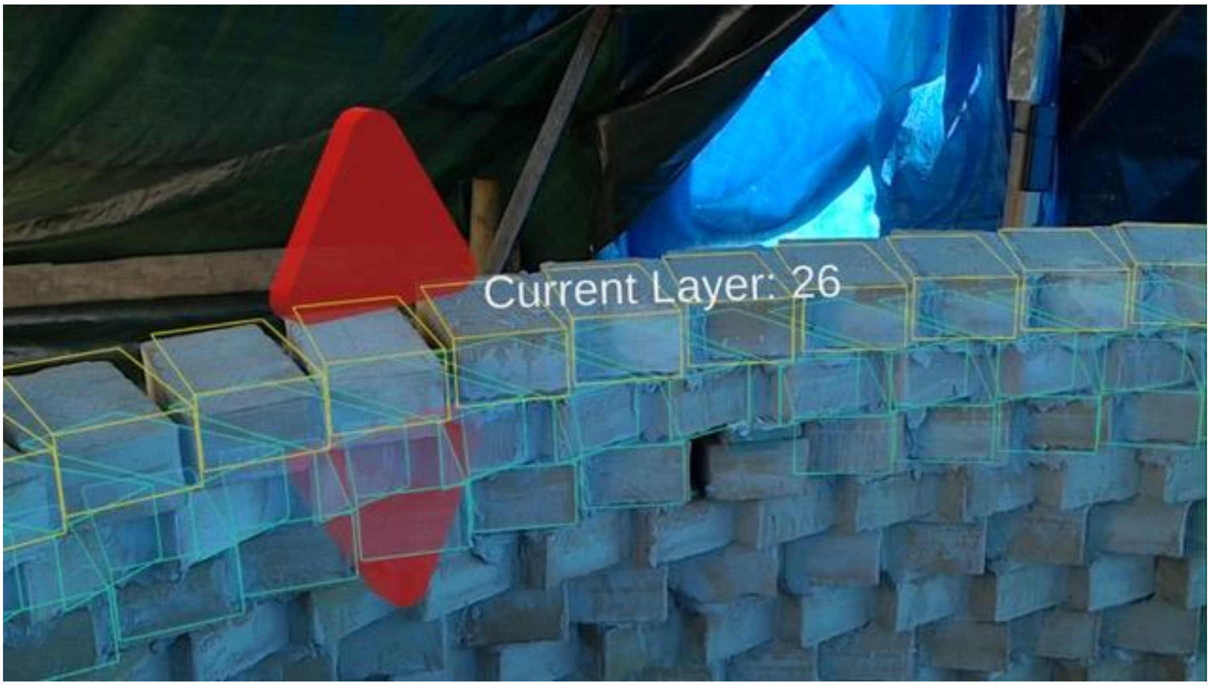

Figure 08: The view through the HoloLens

Fologram is a plugin for Rhino, which allows for the real time sharing of information from Rhino and Grasshopper with the HoloLens. The primary purpose of using Fologram on this project is to translate the digital model from Rhino to the Hololens to coordinate the laying of bricks. To date, there exists two prototype constructions that have made successful use of Fologram's software in conjecture with AR headsets for the purposes of bricklaying. The first of these was a collaboration between the University of Tasmania's Architecture and Design studio in 2018 whereby an undulating brick façade was constructed using this technology (figure 09). This project then lead on to what is perhaps the earliest example of a commercial application of this AR method which was a series of curving brick benches built for the Royal Hobart Hospital in 2019 (Fologram, n.d.; Fologram, 2020).

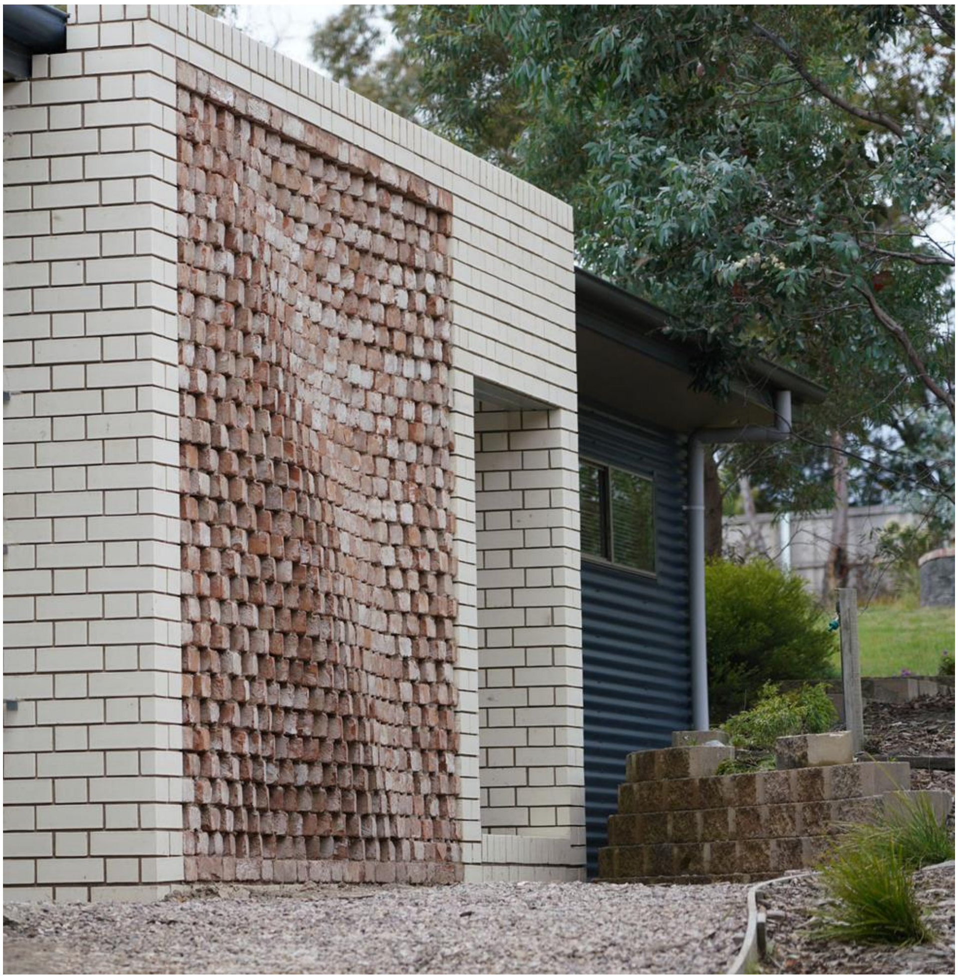

Figure 09: Fologram's complex curved wall at UTAS, an early example of AR guided bricklaying, © Fologram (https://www.archdaily.com/908618/this-is-how-a-complex-brick-wall-is-built-using-augmented-reality)

Additionally, Gramazio Kohler Research at ETH Zürich designed an undulating brick façade for the Kitrvs winery in Greece using a similar system of augmented reality guide bricklayers which is likely the largest scale application of this kind demonstrated so far (Mitterberger et al, 2020). This example did not however use a HoloLens style headset. The method here developed was one in which an assistant worked alongside the bricklayer, holding a sensory input device which sent visual information to a to an augmented reality software, creating a real-time projection of the required brick placement. This is subsequently VR simulation is then projected onto a monitor to guide the bricklayer (figure 10). Projects such as this do demonstrate the potential of AR in construction but in reality, it is still a nascent field. The examples so far given are some of the very few practical demonstrations of the construction philosophy currently built.

Figure 10: Bricklayer and assistant’s hands at work on the Kitrvs winery brick skin, © Gramazio & Kohler (https://gramaziokohler.arch.ethz.ch/web/e/projekte/371.html)

The HoloLens positions itself by scanning its environment and building a low poly model of its environment. In order to coordinate the digital model in the physical space, a QR code can be scanned to create an original plane for the model. Using a physical QR code has some challenges. If the code is moved or deteriorates, it needs to be repositioned and calibrated with the physical construct. If the physical mark is lying on a surface which is not level with the construction site, it is difficult to coordinate with the digital model, resulting in small discrepancies. If there are dense obstacles, walls or columns in the space, this can interfere with the signal and connection between headset and the laptop computer. The virtual objects in the HoloLens are projected one centimetre or more from each eye. This seems to impact the perceived positioning of digital geometry at close range, making the model shift by a couple of centimetres depending on the angle at which you are looking. During construction of the Bothy, the virtual model would inexplicably shift position, resulting in frequent re-scanning of the QR code to recalibrate the model. To resolve this, we had to find a way of correcting discrepancies between the digital and physical 'on the fly'. Scripted virtual buttons were added to the digital model that would allow for 'on the fly' adjustment of the digital model to correct accumulated errors. When the layers of bricks built up, there was also an inconsistency in mortar thickness which led to layers gradually becoming higher than the digital model. The newly added virtual buttons also allowed the HoloLens user to 'nudge' the brick layers in the Z direction. The constant working and refining of the process was a back-and-forth process between the virtual and the real, the digital and the manual. Additionally, there were practical environmental challenges when operating the headset. Bright and changing daylight makes the virtual objects less discernible. For complex or busy geometries day to day it can be confusing, and mistakes are difficult to detect. One simple fix for this appears to be to use a simple sun filter such as that used in sunglasses which would seem to reduce the negative effects from bright sunlight (Skiorski et al, 2020). Another issue was keeping the delicate optical device clean and protecting the digital equipment in a traditionally dirty, abrasive and chaotic environment which beyond careful cleaning and site management were difficult to address. Perhaps, in the same spirit as the solar filter, additional coatings and coverings to shield the delicate components of the device would suffice to resolve this problem.

Code Bothy's construction methodology places it as one of the very few in situ constructions to use AR as a blended approach of craftsmen and data. Where this approach differs from other augmented systems such as those relying on robotic placement of materials is the minimal fashion in which it is transposed over a bricklayer's years of experience with the craft. It elevates the process beyond conventional human limitations of speed and accuracy without removing the unique qualities and advantages of human hands. Additionally, what further sets this project apart is its form. Fologram's work with UTAS and the Royal Hobart Hospital as well as ETH Zürich's work on the Kitrvs winery are promising demonstrations of the potential of the technology but their forms are limited to non-structural decorative elements. Code Bothy differentiates itself as an evolution into a more complex structural form, further reinforcing the potential of AR as sculptural tool. It stands to reason, given that equipment such as HoloLens can be added to the bricklaying workflow relatively unobtrusively, scaling this approach depends only on its adoption by practitioners and their appetite for further experimentation. Code Bothy proves through its form that this fabrication method functions equally well for a standalone vaulting structure as it does for creating complex patterned facades. Furthermore it highlights the opportunity for even more ambitious and complex forms where human hands can still play a valid and essential role.

5. Sustainability and Augmented Ability

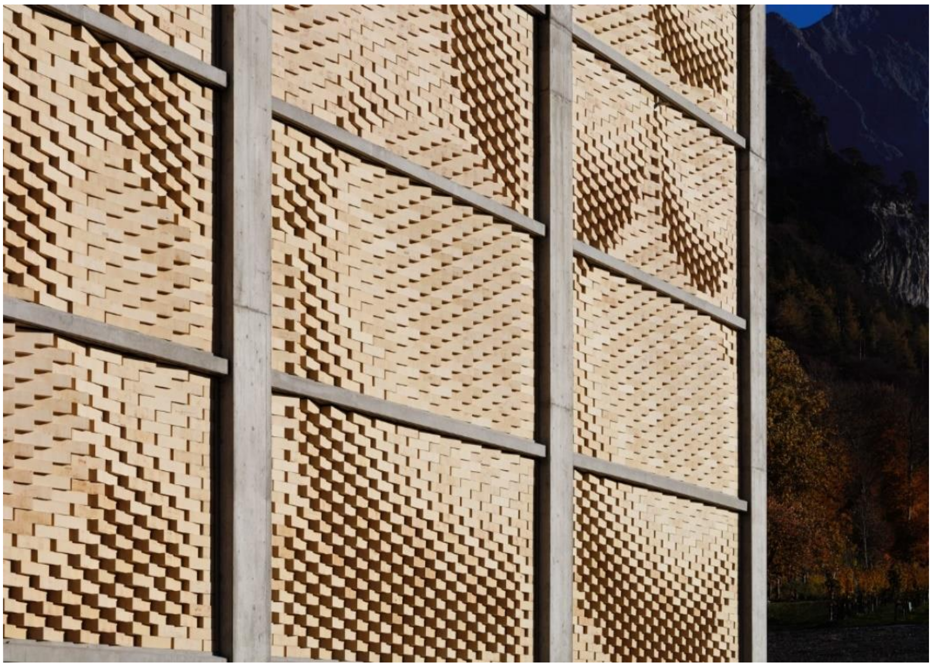

Figure 11: The complex arrangement of bricks of the Gatenbein winery, precisely laid and glued by machine, © Gramazio & Kohler (https://www.archdaily.com/260612/winery-gantenbein-gramazio-kohler-bearth-deplazes-architekten)

When looking into the field of augmented fabrication, we would be remiss to overlook the potential of robotic construction systems. The technology has progressed significantly, from the academic realm into a feasible option for the delivery of complex parametric geometries. Since as early as 2006, robotic bricklaying technology produced the façade of the Gantenbein winery in Switzerland (figure 11), serving as a clear demonstration of the possibility of direct transcription of digital information in tangible architecture (Gramazio and Kohler, 2008). As with all forms of automation, there is much to be said for machine speed and precision. The complex gradients and rippling forms that are possible with a robot become troublesome when attempted under more conventional bricklaying methods (Pedro Sousa et al. 2015). Relying on nothing more than the expertise of bricklayers, complex parametric brickwork is achievable but perhaps cannot match the speed and millimetre precision of a robotic arm.

Figure 12: Bricklaying as reinterpreted by automation, the construction of the Gatenbein winery brick modular panels, © MuDA (https://www.youtube.com/watch?v=FhL-hWPpnzA)

It has been suggested also that not only can a robotic system function faster but also potentially reduces cost by almost half (Dakhli and Lafhaj, 2017). Despite the obvious advantages of this technology, it does have its limitations. There not much flexibility to a system that cannot function outside of very specific and controlled conditions which are certainly lacking in the chaotic building site. Indeed in situ construction is still highly reliant on human hands to dynamically respond to changing conditions and technical inconsistencies (Mitterberger et al, 2020). These technologies also do not lend themselves to isolated environments such as those in highly rural or economically underdeveloped parts of the globe, where traditional methods remain the most pragmatic option for construction (Pedro Sousa et al. 2015). The question as to whether this furthers the art of bricklaying remains. In fact, it's dubious to refer to the particular construction method used by the Gatenbein winery as being an example of bricklaying at all, seeing as one of the two key components is lacking; the bricks are present but the mortar, literally, is nowhere to be seen. The bricks where laid and affixed to one and other using glue to create prefabricated panels in the controlled environment of a factory (figure 12) and the shipped to the winery for installation (MuDa, 2018), rejecting the core in situ principal of the traditional technique. If we cannot refer to this as true bricklaying then is serves more as a facsimile for it, the pattern here serves more value than the implicit quality of the bricks, their structural properties and the precision with which they were placed.

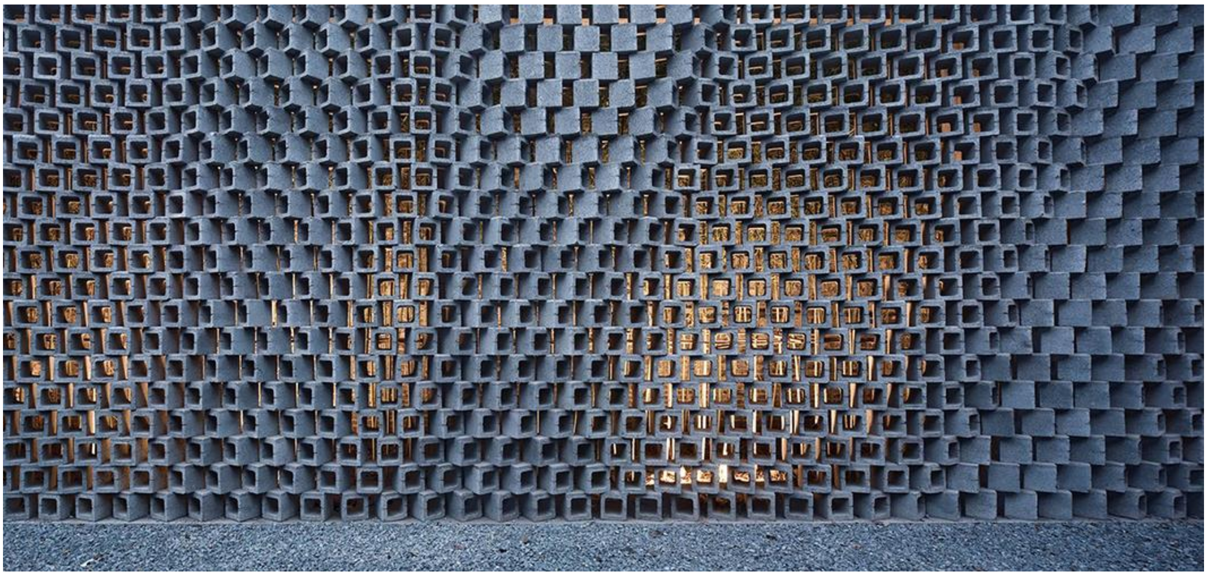

Figure 13: Archi Union's reskinning of an old silk workshop, © Shen Zhonghai (http://www.archi-union.com/Homes/Projectshow/index/pageid/4/id/47)

Archi-Union Architects where working with the constraints relating to achieving a complex digitally generated façade but without access to a robot to fabricate it or augmented reality system. Cinder blocks were the brick of choice for creating an abstraction of the waves of billowing silk, the fabric previously produced in the former industrial building onto which this complex façade would be affixed (Divisare, 2017) (figure 13). Their task was to convert algorithmically composed patterns into tangible architecture, achieving this with analogue templates cut with the precise angle profiles of the blocks to allow the bricklayers to place them in the correct orientation (figure 14). Interestingly, through a lack of more advanced robotic equipment and their rudimentary method for mimicking the speed and accuracy of this technology, Archi-Union had stumbled onto what we might call an early iteration of AR bricklaying. Much like with earlier video projection mapping methods (Pedro Sousa et al. 2015), simple technology was here used to facilitate the transference of digital information into an architectural reality. By necessity they had to rely on human hands and craftsmanship to achieve these results as the use of robots was not a practical option here.

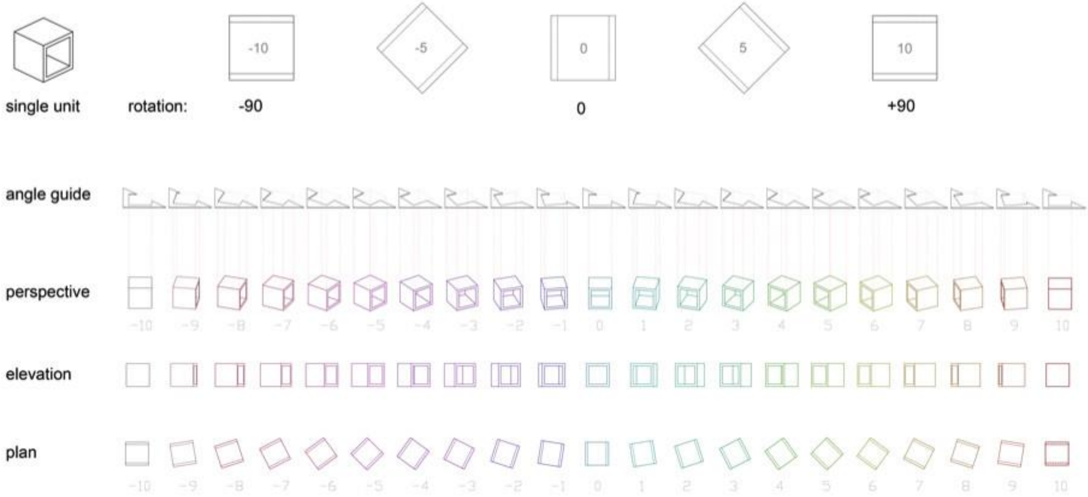

Figure 14: A range of templates representing the total number of orientations require, © Archi-Union (https://www.archdaily.com/82251/au-office-and-exhibition-space-archi-union-architects-inc)

According to Richard Sennet, the craftsman's skills are developed over time with continued practice, to the point when bodily movements are ingrained and the process of making becomes automatic. If robots can be programmed to do the same without extensive practice and time involvement, why do we continue to lay bricks by hand? This project seeks to occupy a design-based ground for research in between this divisive issue. It is important to go back to Gramazio and Kohler's robotic brick laying, 'Pike Loop' in New York 2009 was the first ever in situ automated construction of a brick wall. 'Programmed Wall' and 'Pike Loop' were not ordinary brick walls, even though they were made with ordinary bricks. These two walls were designed to be sculptural, in order to show the potential of a robot making a wall versus a mason. For Gramazio and Kohler, walls built by robots can afford the brick an infinite number of design configurations and patterns without 'extra effort'. Unlike the brick layer, the robot has the ability to position each individual brick in a different way without optical reference or measurement'. Therefore, the overall wall designs were in reference to unique 'spatial disposition' and 'procedural logics' (Gramazio Kohler, 2020). All the variations of a robotic brick wall did not perform any differently compared to the wall made by hand with a standard brick course. This set up a key position for Digital Manual: that the added value was in design. One aspect of the research work was situated in design, that becomes achievable if Sennet's craftsman can also function like a robot. The amalgamation of the craftsman and the robot also points to how we learn to make or practice, when we are loaded with augmented ability.

Code-Bothy looks towards a fabrication process where in theory any digitally modelled design can be replicated by hand by any sufficiently skilled craftsman. Digital model of the Bothy is not just the starting point but also arena for design expressions. Each step of the design decision making process requires years of training and practice. Engaging designers and craftsmen in a mixed reality environment is the opposite of deskilling. With increasingly complex geometries generated by computer software without any knowledge of physical fabrication, it is down to the makers to decipher details of production. One can argue that this is an effective way to sustain manual skills through a collaboration between digital and hand modelling. Our work directly with the bricklayers allowed for a deeper understanding of how we can approach our digital designs, by both respecting their limitations and pushing boundaries of their crafts. Virtual worlds are valid cavasses alongside the physical. Digital and manual instruments are tools to design and make. Together, these two realms and working methods is in itself a domain. Our design languages operate precisely in the context. To think and work digitally and manually is not a reductive or diluted endeavour from the two ends of this spectrum. Rather, a way legitimately to spell out a bond between them.

Figure 15: The subtle angle change of the brick arrangement is highlighted with direct sunlight

Digital design demands a re-examination of how we make. The digital and the manual should not be considered as autonomous but as part of something more reciprocal. One can engage with digital modelling software or can reject all digital tools and make and design by hand, but can we work in between? Working digitally and manually is about exploring areas in design and making: manual production and digital input can work together to allow for the conservation of crafts, while digital fabrication can be advanced with the help of manual craftsmanship. In the context of mixed-reality fabrication, the real and virtual worlds come together to create a hybrid environment where physical and digital objects are visualised simultaneously and interact with one another in real time. Hybridity of the two is compelling because the digital is often perceived as the future/emergent and the manual as the past/obsolescent. The practice of being digital and manual is on the one hand procedural and systematic, on the other textural and indexical (figure 15).

6. Conclusion

In the 1830s, William Henry Fox Talbot – the English inventor of photography – used a camera lucida – essentially a pin-hole camera that reflects the scenery being viewed, allowing for it to be copied by hand – to help him draw the beautiful surroundings of Lake Como in Italy. He was, however, frustrated with the outcome, and in a letter to the journalist William Jerdan lamented the limitations of using this early mixed-reality tool for copying: 'These inventions… assist the artist in his work; they do not work for him. They do not dispense with his time; nor his skill; nor his attention. All they can do is guide his eye and correct his judgement; but the actual performance of the drawing must be his own' (Talbot, 1839). The eventual solution to Talbot's problem was to 'fix' the reflected image on paper in the form of a photograph. Today, digital mixed reality presents users with the augmentation of analogue principal of projection. Instead of a camera lucida, we have HoloLens and if craft making can indeed be enhanced by digital technology, the implications are wide ranging.

Figure 16: Laser cut physical model of Bothy against the brick texture

Looking through the HoloLens is akin to wearing oversized goggles and seeing one's surrounding overlaid with a translucent Microsoft desktop. In order to interact with the built-in computer, the wearer needs to make particular hand gestures to navigate the various menus. When a digital model is loaded and scaled at one to one, a 3D model identical to the one on a computer screen will appear. It is possible to move, rotate and even walk around the virtual structure. At Grymsdyke farm, we tested the HoloLens with the craft of bricklaying in the construction of a bothy (a small brick enclosure). During construction, the bricklayers 'turned on' layers of virtual bricks, one layer at a time, and laid real bricks in place of the virtual ones. All the key decisions about structure, design and geometry were made in the creation of the digital model. In this mixed reality, the bricklayer simply focused on positioning the bricks. The space taken up by mortar was represented by gaps in the digital model. In order to fill these gaps, the techniques used by the skilled bricklayer were indispensable. The messy process of applying the mortar called upon the bricklayer’s timing, dexterity and trained movements. One can argue that an onsite mixed reality construction, as such, cannot do without humans. Unless the digital model is 3D printed, limiting size and materials used, translation of the digital model into physical reality decisively involves human craft, akin to Talbot’s fixing of projected light as photograph.

This human factor can be enhanced with the help of digital technology: jigs and physical guides can help with making and precision of final outcome, but they are limited by the physical attributes of the tools themselves (figure 17). Digital design, meanwhile, allows for more geometrical solutions without repetition – in the case of the bothy, acting as a guide for the bricklayer. The incorporation of digital design, however, can only be achieved if we can sustain the continual pursuit of manual workmanship. Sustainability in the design industry and architecture is not about human versus machine. The difficult question for us as a community of makers is how we can address the training and education of crafts. Whether it is a dance with digital tools, a conversation with the past or a wrestle with technological development, the dialectics of design and making must be inclusive and balanced. Whatever the digital future holds, whenever the ubiquity of automation looms, one cannot help but suspect that the human element of design, particularly in crafts, will not completely disappear.

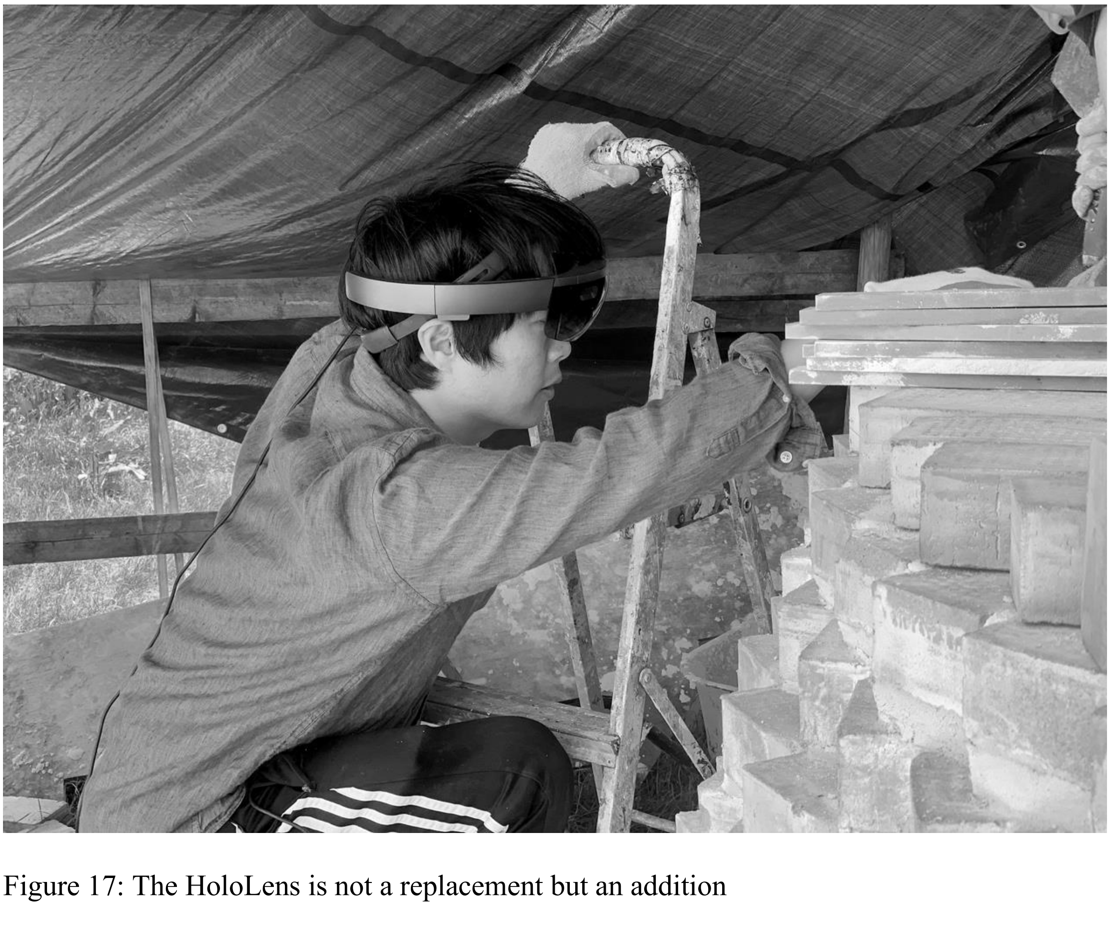

Figure 17: The HoloLens is not a replacement but an addition

Figure 18: Night view of the Bothy at Grymsdyke Farm

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