

COMBINATORIAL DESIGN: DESIGNING COLLABORATIVE MODELS FOR CONSTRUCTION (MAX. 95 CHARACTERS INCLUDING SPACES)

N. TOPIC - 2

N. FOCUS – 2.a, 2.b, 2.c

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Abstract (max. 600 characters including spaces)

The paper introduces and discusses “Toolkit for Collaborative Construction”, an Augmented Reality (AR) tool for Modern Methods of Construction (MMC) developed out of the authors’ research on and implementation of novel combinatorial design methodologies using a engaged scholarship, or values-centred, approach to automation. The paper outlines both the wider context of the integration of automation into processes of the built environment and the development and prototyping of the Toolkit as a set of technologies and workflows towards a novel approach to MMC that is localised and community centered.

Keywords: Combinatorial - Augmented Reality - Automation - Modern Methods of Construction - Collaborative Production

Introduction

At the core of the authors’ research at The Bartlett School of Architecture’s Automated Architecture Labs (AUAR Labs), and the spin-off consultancy Automated Architecture Ltd. (AUAR), is an ambition to change the way in which we build by utilising a values-centred approach of engaged scholarship, establishing new processes of collaboration in two ways. The first is by using co-design between non-expert or specialist users of digital design and assembly workflows, and the second is through interfaces of human-machine interaction through rethinking traditional construction workflows to enable use of these tools by non-experts.

A reconsideration of these workflows is necessary as the construction industry internationally is among the least digitised and has been experiencing an industry-wide productivity lag since the mid-20th century (Bughin et al, 2016). Existing Modern Methods of Construction (MMC, an umbrella term encompassing both off-site construction technologies and novel onsite technologies (Nawi et. al, 2014)) that aim to rejuvenate the sector by implementing automation and prefabrication - such as companies Bryden Wood, Urban Splash TopHat in the UK, or Kattera in the US - generally centralise their production in off-site factories, disconnecting their systems from the contexts they are deployed in, and alienating local communities and trades further through the use of centrally deployed ‘installation crews’. In combination, these factors result in MMC being seen as displacing local jobs, which in turn leads to resistance and scepticism as well as limited localised capacity for MMC (Mean et. al, 2017), and can be considered to be further exacerbated by the fact that automation tends to affect those who are already disadvantaged more significantly (Benjamin, 2019; Eubanks, 2018).

With the ‘Toolkit for Collaborative Construction’, the authors present a participatory approach to Augmented Reality (AR) and MMC systems for housing in the form of a platform for local communities of both lay and trades people to engage with these technologies, and create knowledge for the design and realisation of contextualised MMC housing solutions. This paper presents both the ‘Combinatorial Design’ App and its accompanying MMC system Block Type A, designed in-house to facilitate the technical portion of the Toolkit, as well as its collaborative design development through two community-based groups of project participants.

Methods

The ambition and novelty of Block Type A consists of its use of a highly reduced family of combinatorial elements for the design and construction of structures of any scale, from pavilions to family homes. Discrete elements are universal ‘Lego blocks’ that can be assembled in a number of different ways to generate different outcomes using the same, self-similar elements, or what is referred to as a ‘kit of parts’ (see Figure 1). The key concept the system follows is that of ‘digital materials’ as defined by Gershenfeld and Popescu (2009), meaning the reversible assembly of a discrete set of components, based on a logic of serialised repetition. This approach was developed by AUAR Labs through three design research projects at the scale of 1:1 pavilions for the Tallinn Architecture Biennale (2018), Royal Academy (2019), and the case study project ALIS (Automated Living System). Discrete elements can vary in size, but will typically retain one scale across a system which is adaptable throughout its life cycle as a building. Block Type A elements are entirely digitally fabricated ‘boxes’ assembled from six pieces of CNC’d sheet timber, with internal frames for stability and predefined, repeating holes for connections between blocks. The system uses a mix between global and local (or discrete) post-tensioning with steel rods, nuts, and bolts for rapid construction (see Figure 2), a method that does not require

specialist training.

This approach is underpinned by the Combinatorial App, a web application that can be used on mobile and desktop with an intuitive interface that acts as the design space of a modelling software (see Figure 3), enabling the user to design their Block Type A structure, and anAR App using Unreal Engine, a physics engine by the gaming company EPIC Games.

The Combinatorial App features a straight-forward 3D environment that can be navigated and interacted with using arrow buttons. The placement and movement of elements has been designed to be intuitive - the zoom function is activated by pinching two fingers towards or away from each other on mobile, or scrolling the mouse wheel up and down on PC. The AR feature of the toolkit is used to overlay assembly instructions or robotic toolpaths on the physical environment. To this end the team developed a communication pathway between Unreal Engine and industrial robots, whose paths as well as predicted outcomes are then visualised in ARCore. Where possible, structures devised on the application can therefore be assembled using robots. Alternatively, the AR feature can also instruct steps for manual assembly of the elements.

The technical components of the Toolkit hence afford an accessible, one-stop-shop tool that can be used for modelling, as well as materialisation and customisation in real time, linking together computational design and digital fabrication in a new way, achieving a fully-integrated virtual to physical workflow interface. By improving accessibility to MMC products in this way, the Toolkit for Collaborative Construction aims to democratise their use and implementation in local settings, and to empower collaboration with the community through responding to their needs and reducing cultural barriers to MMC and automation.

To develop this component of the Toolkit in a manner that is holistically inclusive and participatory, and to facilitate accessibility and incentivise discussions around automation and housing in communities, AUAR/AUAR Labs have been holding workshops of varying formats over the past year.

An initial series of two workshops titled ‘Housing with Automation’ held in UCL’s facilities in Hackney, East London in mid-2019 and early 2020 invited local council representatives, building craft students and community representatives to express their views on and learn about automation in construction, and co-design activities held within, surrounding, and alongside a 1:1 Block Type A structure to be realised by AUAR in late 2020. These workshops, designed by AUAR Labs in collaboration with social scientist Claire McAndrew and participatory artist Caroline Williams, constituted a two-stage process towards a meaningful integration of the local community into the design process of the prototype.

The workshop series ‘Making Together’ in partnership with Knowle West Media Centre (KWMC), Bristol, was then devised to test both the technical architecture and accessibility of the Toolkit by engaging with non-experts interested in digital housing production, using insights obtained from the exchange and collaboration with the Hackney cohort as starting points for conversations and activity planning. Knowle West is a council-built estate situated in Bristol, south-west United Kingdom. Its 13,000 inhabitants have a high level of disadvantages and in-work poverty, as well as a prevalence of low-skill, low-productivity jobs of the kind often cited as at risk from automation. At the same time, the area has a high number of people in the construction trades, and is actively looking for means to solve its social and economic issues. Knowle West therefore provided an ideal testing ground, as it faces circumstances similar to a number of regions in the UK and across Europe and North America. The Media Centre supports and facilitates projects and collaborations in the community, and also operates The Factory, a making and training space offering access to digital manufacturing technologies such as CNC machines.

The workshop series was held in two modalities, one version for trades people, and one for the wider community. In a first “taster workshop” on 22 February 2020 (see Figure 4), attendees participated in a range of activities centered around perceptions of technology and living spaces, such as conceptualising and building their “dream robot” prototype for their home, and thinking about their own requirements for a house, such as the minimum space needed for functions like cooking, sleeping, etc. and the ideal layout of a house. Through these activities, a culture of discussion was formed that makes potentially charged topics such as automation accessible through familiar concepts.

Given the current global COVID-19 crisis, the rest of the workshop series had to be moved online. Both cohorts attended a set of four further workshops virtually, developing understanding of and interaction with the Toolkit through tasks tailored to the respective skillsets, and ultimately designing their own structures using the Combinatorial App. In each workshop, the participants were given task sheets to fill out and engage with the ideas of the Toolkit. For the community participants, this was initially focused around their homes, whereas the trades participants were asked to think about the tools they use in their work, and how the associated processes and movements could be ‘encoded’. Through these tasks, and an introduction to and questions about automated technologies, the foundation was laid for a better understanding of the opportunities the Toolkit can provide both for the single participant, and the wider potentials of AR and MMC in the industry. The workshop series culminated in an exhibition on Mozilla Hubs, in which the participants showed 1:1 virtual prototypes of their designs, and shared their thoughts on the Toolkit and learning experience via embedded audio files (see Figure 5).

The second set of workshops was then focused around delving into the architectural logic of discrete systems in general and Block Type A. Participants physically built their own structures using model blocks delivered to them by AUAR Labs, with the goal to think about how they would change their homes, and designed their own

building components to be made out of sheet timber and fabricated using CNC machines. Having familiarised themselves with the Toolkit's building structure, participants were then introduced to the Combinatorial App platform and its interface through a set of tutorials prepared for them. The app features a straight-forward 3D environment that can be navigated and interacted with using arrow buttons. The placement and movement of blocks has been designed to be intuitive - the zoom function is activated by pinching two fingers towards or away from each other on mobile, or scrolling the mouse wheel up and down on PC. This process was continuously assisted by AUAR Labs staff through Q&A and support sessions on Microsoft Teams, and reflected on in cohort discussions on Teams or Zoom. The tasks increased in complexity over time, and the participants were asked to either individually or in a group design various structures related to their work or home, respectively - these ranged across scales from small pieces of furniture to entire living spaces. This set of workshops was from the start conceptualised to also include the physical collaborative build of a structure based on the participants' designs in front of Knowle West Media Centre - due to the pandemic, this was initially postponed but will go ahead in autumn 2020.

Results & Discussion

The Toolkit for Collaborative Construction constitutes an accessible, engaged scholarship, or values-centred, approach for the increased adoption and localised application of automated technologies and MMC. While the Combinatorial App included in it presently only supports the MMC Block Type A developed by AUAR, further development steps will be undertaken to allow for the integration of other MMC systems, which will be necessary to make broader adoption of the Toolkit possible. Regarding the technical portion of the Toolkit, participants from both recent cohorts reported finding designing with the Combinatorial App a comparatively intuitive process after introduction to it through AUAR team members. However, the participants also highlighted the importance of the ongoing tech support throughout the project, particularly because some experienced problems accessing the App through certain Internet browsers, and/or hardware compatibility issues.

Naturally, the necessary move from in-person to virtual application and development of the Toolkit for Collaborative Construction also significantly altered the trajectory of the project. In this regard, participants reported some problems due to the new workshop mode, however these were mostly limited to unfamiliarity with the platforms used to host the sessions, e.g. Zoom and Teams. The final exhibition from the first set of workshops was well received as a community event, and in general participants from both cohorts emphasised their enjoyment of the collaborative spirit in both the design work and surrounding discussions. Some differences could be pinpointed in the experiences of the trades cohort compared to the community group - as one participant worded it in their feedback, 'people from different backgrounds ask different questions'.

Participants in the community group were given kits to build physical blocks, and reported these were more straight-forward to work with than the App. Regarding the MMC system itself, this cohort reported that the discrete nature of Block Type A was very helpful insofar as they only had to consider one geometry and could therefore focus better on the design of their objects and spaces. Furthermore, the feedback also included that using the same element for different functions helped the participants question standard processes and procedures, and look for novel ways of solving problems. Among the challenges reported by this cohort besides technical issues were understanding the limitations of the system virtually and physically, and difficulties of communication due to the remote working situation. All participants emphasised that they much preferred collaborative over individual design tasks, with one participant stating, 'we are the community designing!', but would have preferred to be able to share ideas face to face. Participants also stated that they had gained confidence to combine the new skills acquired in the project with their existing skill sets in designing, manufacturing and constructing spaces.

The trades cohort also emphasised the value of the collaborative processes and their ability to highlight and complement participants' different professional backgrounds, with the participatory approach bringing together logical/mathematical thinking oriented and creative/artistic viewpoints. This diversity, according to one participant, in conjunction with the workflow of the Toolkit, moved the focus away from 'getting it right' to generating new ways of thinking, because the approach allows for diversity and flexibility instead of standardisation. This participant felt that working with the Toolkit gave them 'permission to challenge the conventional and be more involved with the design'. Another participant, who works as a builder, stated that working with the App allowed them to think differently about design workflows and looked forward to integrating some of their new skills into their construction work. The changing scales and interactivity of the system were also mentioned positively, especially both with regards to their capability to bring people together in public spaces in an agile manner, and to diversify the physical world through the digital.

A general perspective presented in the feedback from the cohorts was a desire to connect in person and participate in the physical realisation of a Toolkit structure when the COVID-19 situation allows for this. Due to the pandemic, the construction part of the project as well as the inclusion of robotics and AR in it had to be postponed, but the AUAR team facilitated discussion and knowledge transfer around this regardless through online discussions, virtual demonstrations and presentations; participants stated that following this, they were

also interested to further the conversation around human-machine collaboration, and automated technologies in construction.

Conclusion

Modern Methods of Construction promise faster and cheaper workflows for the built environment, but in their present iterations tend to neglect the need for localised, participatory approaches to foster acceptance of and engagement with new technologies by professionals and the public alike. AUAR/AUAR Labs work argues for an implementation of automation in the AEC industries that emphasises the collaboration between human and technology in a manner that produces complementary workflows. By utilising easily accessible materials such as sheet timber and offering frameworks that can be fabricated without the need for specialised factories or skill sets, modular solutions popular in MMC systems can become part of the construction sector already local to the place they will be deployed in, strengthening the local economy and shortening production chains. Through training and empowering trades people and communities to explore such technologies in values-centred knowledge transfer sessions, the Toolkit for Collaborative Construction can open up discussion and adoption of ‘truly digital’ (Popescu and Gershenfeld) workflows from design to construction.

Furthermore, the ambition to provide a truly accessible platform for MMC processes necessitates the design of such processes in a manner that allows for intuitive engagement with them - placing at the forefront a user’s values - rather than complicated interfacing of a number of different soft- and hardware solutions. Given the comparatively early stage of its development in relation to the user experience, it can be concluded that the Toolkit for Collaborative Construction can provide a “one-stop shop” solution for design and assembly, offering an integrated system for sustainable, affordable construction that is community-based through the Block Type A system. In next steps, the construction part of the Toolkit will be tested in a test build in Knowle West, Bristol, UK. Furthermore, to facilitate a more mainstream adoption of this approach, future developments will implement the ability to support other MMC systems on the Combinatorial App.

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