Design Robotics

Towards human-robot timber module assembly

Dagmar Reinhardt[1]
[1] *The University of Sydney, Aarhus School of Architecture*
[1] *dagmar.reinhardt@sydney.edu.au*

This paper presents research into an ecosystem of human-robot collaborative manufacturing of timber modules that can respond to diverse environmental conditions through construction tolerances. It discusses the design and robotic workflow for two case studies with unskilled participants in an academic context, for the production of non-standard spatial and structural scaled prototypes that develop new systems for thinking and making architecture.

Keywords: *design robotics, timber assembly, human-robot collaboration*

INTRODUCTION

Industrial robots transform architectural production by establishing a different relationship between construction machine and building processes (Gramazio and Kohler 2016). This further advances design processes of computational modelling, scripting and analytical simulation that streamlined workflows from design to production (Scheurer 2013, Kolarevic 2008). With the introduction of 6 axis robotic design and manufacturing, we are now moving into a space of machine learning, computational material practice and collaborative advanced manufacturing (Bechthold 2013). Hence, in a context of industry 4.0, new possibilities in the design and implementation of digital interfaces for robotic control are available. The ubiquity of industrial arms will in the future inform the role that advanced manufacturing tools enable design and processing techniques, towards customization and singular and bespoke solutions for design and architecture practices.

Beyond automated and optimised manufacturing processes, robot arms can be used as versatile, multi-axis production tools that can create an ecosystem of human labour and machine labour. In a context of design robotics, this ecosystem can be investigated as the balance between standardised and module production on one side, and the unique and singular results accessible within an adaptable parameter framework on the other side. Sequences of robotic and manual craftsmanship can be embedded, so that in the future (industry 4.0) humans and robots can collaboratively work together (Flusser 1999).

This paper presents and discusses empirical research into computational design and robotic assembly with standardised timber elements in the variant production of multiple, 1:2 scale prototypes in additive fabrication. It introduces 'robotic fuzzy modules'; elements that are both generic (in the sense that they are mass customised), and specific (unique in their making). These modules are adaptable through an inbuilt margin that seconds operational tolerance, and enables a spectrum of constructive solutions for spatial expressions. The dexterity and cognitive abilities of humans augment here the precision and repeatability of robot movements.

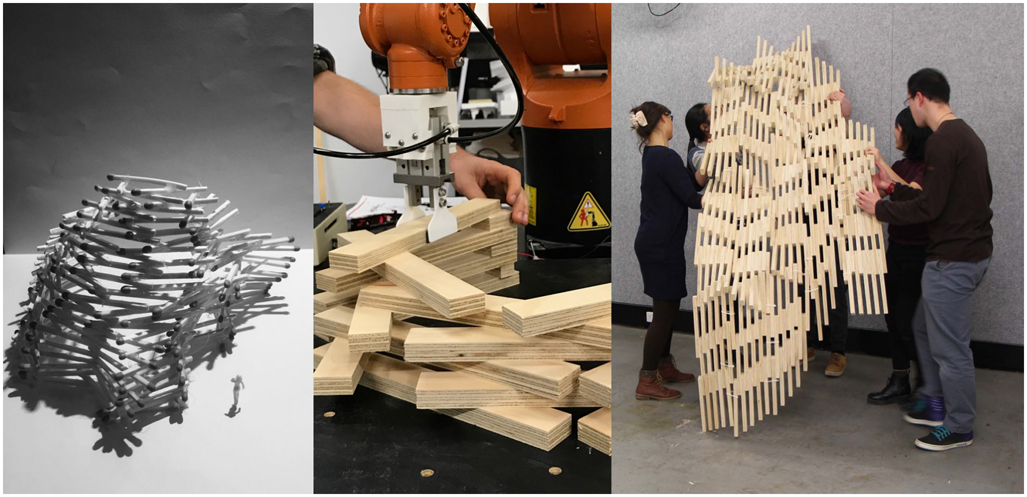

Figure 1
Case Module A: analog concept model (a); robotic stacking (b); human construction of assembled modules and positioning (1:2 scaled prototype, c).

DESIGN ROBOTICS

Coupling robotics with iterative design strategies and material manufacturing variation can be particularly relevant for novel work process. Manufacturing paradigms to date were confined to available fabrication axes, with specific approaches utilising sophisticated tailorable materials. In contrast, a robot's dexterity can be freely designed, programmed and customised to suit a particular constructive intention, both at conceptual and material levels. The customisation of standard tools as robotic end-effector allows for multiple production methods to be sequenced and consecutively undertaken by a robot.5 Singular processes of additive, subtractive or formative robotic fabrication (for example combining routing, milling, drilling, welding, gripping) can be controlled with precision, establishing a relationship model of 'tool-process-outcome' that is affordable, accessible, and reliable. This promises feasibility for customisation of existing building and construction methods and already enables architects to find new solutions for a standard material palette of timber, concrete, steel and brick. But it also opens entirely new and radical approaches for physical relationships in time, such as discrete element assembly, incremental and force-based forming of sheet material, or plasticity-based deposition of fluid material bodies. Material sophistication can be achieved through the ability to control physical properties, in conjunction with sensor-based data feedback on material behaviour and robotic tooling process.

As a context for this research, the paper reflects on the conceptualizing, designing and implementing of the experimental digital interfaces for robotic control and manipulation. Participants were introduced to fundamental principles in robot modeling: mathematical foundations, analog approaches and coding transfers, robotic kinematics and path planning. These approaches fundamentally transform our way of thinking about building and buildings, by developing fabrication processes in architectural robotics that differ considerably from the repetitive routines of industrial automation.

CASE STUDIES

Two robotic case studies are presented which explore different constructive strategies for the design of a timber structure assembled from short, generic, industrial widely adapted timber elements as a cheap and customisable building material. The layered/nodal constructive system allows for a flexible response to local structural requirements. The framework for the case studies comprised of timber specifications (element dimensions, numbers, connective points); robotic reach; workspace and dimension of structure in space; choreographic sequence between robot and human actions.

Robotic design processes commonly embed a number of phases (this is valid for most):- Defining the Problem- identifying the purpose of a construction- identifying user and application- identifying specific requirementsResearching and designing- gathering information about precedents and methods- identifying specific details of the design which must be satisfied- identifying possible and alternative design solutions- planning and designing a appropriate structure which includes drawingsCreating a Prototype- testing the design- troubleshooting the designBuilding the robot demonstrator type (endeffector, or full machine)- Programming and testing the robot- Evaluation of robot, process and prototype- evaluate the design- evaluate the planning process

CASE STUDY 1

In the first study, 15 timber elements were robotically assembled (KUKA Kr10) to constitute a set of 5 differentiated modules, with the human collaborator fastening each layer. 30 modules were then interlocked and constructed into a 1: 2 spatial prototype.

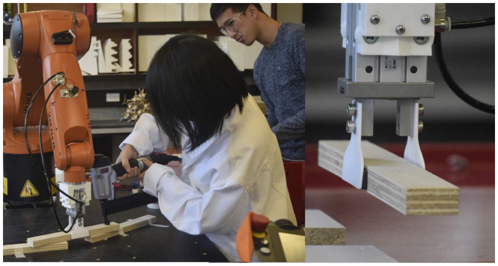

Figure 2
Case Module A: robotic positioning of member (right); and human collaborator fixing elements (nailgun, left).

CASE STUDY 2

In the second case study, 8 timber elements were robotically assembled in a base module, whereby the robot moves to an exact position in space for each timber element, referenced back to the geometrical information maintained in the database. Afetr positioning, the human collaborator fixes each timber element manually for each node. The series of modules was then further assembled into two interlocking 1:5 scaled tower prototypes. The design and robotic programming further investigated the potential for a broad spectrum of constructive solutions, based on stacking or intersection strategies, and dependent on the structural integrity and performance of the overall design. Both studies explore assembly variations of modules with a simple constructive rule, in order to test, determine and optimise the human-robot collaborative building sequence.

DISCUSSION

The paper reviews these robotic case studies not as finite manufacturing products but as structural strands that are non-normative and non-regular. Where robotic workflows are customary based on precision and optimisation, here, the human-machine collaboration is considered as an integrated task palette, where multiple actions come together. Instead of fully defining the geometrical form, the modules are primarily driven through an assembly logic that is marginally determined, and thus programmed to be capable of responding to a local context both through flexibility and specificity. These studies bridge between robotic motion, gestural tracing and material assembly. By creating interfaces that rethink robots as instruments for architects and designers to develop processes and protocols in material, time and space (rather than robotic applications that merely execute objects), the scope for architectural practice is expanded. Though six-axis robots in industrial settings are generally programmed to iteratively execute identical tasks, these case studies demonstrate the potential for a more dynamic and open line of assembly. Moreover, this enables

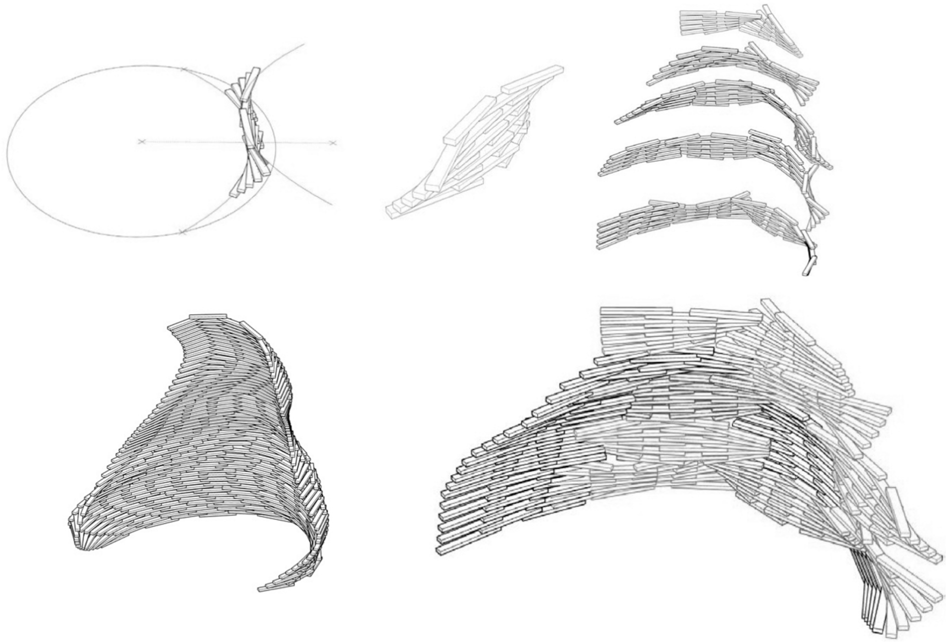

Figure 3
Case Module A: robotic workspace and module assembly of standard timber elements (a); 5 types of finger modules across one overall figure (b); variations of overall stacked geometry (c) and final reconfigurable spatial prototype.

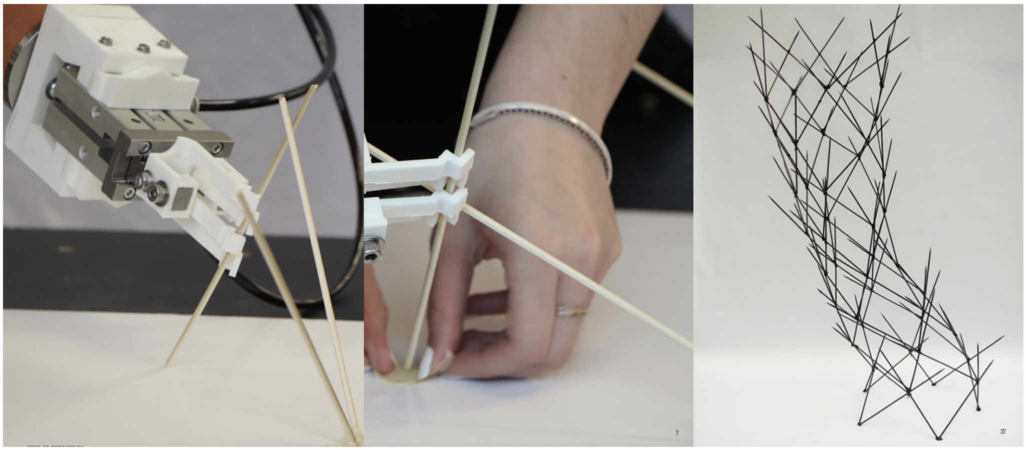

Figure 4
Case B Module: robotic positioning of timber member (a); human collaboration with fixing node points (b); singular unique tower strand composed of module series (scaled prototype (c).

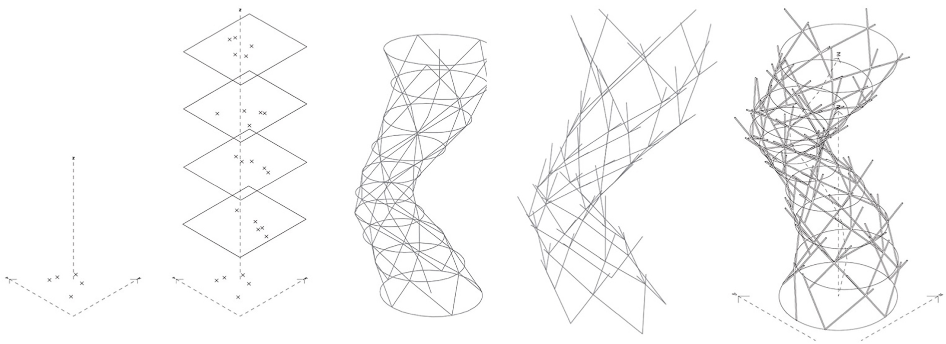

Figure 5
Case B Module: Series of 5 points placement (a); process 4x repeat with equidistance between grids (b); series of interconnected curves with equal plate distance (168mm, c); and assembled modules across vertical stream (d).

Figure 6
Assembled module system, series 3.

humans and robots to collaborate and working together side by side safely, producing unique rather than standardized elements.

[further discussion of case studies and student work embedded here from google]

CONCLUSION

Architectural Practice, Entrepreneurship and the Future of work whereas computer science and architecture robotics community focus on radical transformations of interdisciplinary practices,sensor-feedback and onsite construction implementation,8 arts and social sciences communities query the value and long-term impact of robotics on human living conditions, and the future of work.9 When robots are taking over work from us, is that in support of unwanted or heavy labour, or isour work - in the sense of action, creativity, engagement, collaboration - taken away fromus? And beyond the fact that in the future and work and process that can be automated will be automated, how can the enhancing capabilities of robots expand the horizon of our possibilities? Significantly, industrial robotics and specifically the sharing of robotic applications and manufacturing technologies in workshops and open platforms will allow us to evolve from initial experiments to industrial processes gradually. By democratising a practical understanding of how designs, toolpaths, material formations, robotic protocols are constructed, the robotics community is demonstrating strong support for the establishment of startups and entrepreneurship.

REFERENCES

Bechthold, M 2013, 'New Strategies For Material Systems Research', in Peters, B and Peters, T (eds) 2013, *Inside Smartgeometry - Expanding The Architectural Possibilities Of Computational Design*, Wiley

Brell-Cokcan, S and Braumann, J (eds) 2012, *Robots in Architecture, Art and Design*, Springer

Flusser, V 1999, *The Shape of Things*, Reaktion Books, London

Gramazio, F, Kohler, M and Willmann, J 2014, *The Robotic Touch – How Robots Can Change Architecture*, Park Books, Zurich

Kolarevic, B 2008, *Manufacturing Material Effects: Rethinking Design and Making in Architecture*, Routledge, New York

Moggridge, B 2007, *Designing Interactions*, MIT Massaschussetts

Negroponte, N 1969, 'Toward a Theory of Architecture Machines.', *Journal of Architectural Education (1947-1974)*, Vol. 23, No. 2 (Mar., 1969) (1969), p. 9