SPOOL

Cyber-physical Architecture #2

Apparatisation in & of Architecture

V6/#1

ISSN 2215-0897
E-ISSN 2215-0900

VOLUME 6 . ISSUE 1

Discrete Robotic Assemblies

Towards an automated architecture

Manuel Jiménez García, Gilles Retsin, Vicente Soler

Bartlett School of Architecture
University College London

Abstract

The projects featured in this paper aim to demonstrate the potential of Discrete Robotic Assembly in architecture. Although still in its early stages, this research proves that there is an increase in construction efficiency within a discrete design framework. The research shows how a limited set of assembly possibilities eases the automation of the manufacturing process and leads to a reduction of labour, construction time, and cost. This intrinsic link between discrete design methods and automation hints at a potential shift in the construction industry governed by a new paradigm in computational design, where architectural elements are defined from and for automation.

Keywords

robotic assemblies, automated architecture

Introduction

The use of industrial robots in architecture schools has proliferated during the last decade, leading to a large variety of small and medium scale structures featuring automated processes in design and construction. However, the use of these processes has mainly focused on the pure automation of human actions, establishing workflows mostly based on the post rationalisation of continuous topologies. Many of those examples are based on a proto-parametric approach (Schumacher, 2016), in which parts are intrinsically adjustable and continuously differentiated.

The work in this article questions the acceptance of a continuous paradigm within robotic fabrication. It instead proposes a model based on a discreteness, in which building elements combine together into larger assemblies, rather than being described from the rationalisation of a whole. This argument is based on both the questioning of the "digital" in architecture and technical concerns in the search of a new design model within automation.

Gerschenfeld, Carney, Jenett, Calisch, and Wilson (2015) argue that digital fabrication is caught in a permanent conflict between complexity and speed and that it can only achieve both if it becomes discrete and "digital." They go on to say that a process or operation can only be considered digital if it operates on a material that itself is digital. Otherwise, we are still in an analogue process.

Digital data is based on a discrete, discontinuous representation of information, whereas analogue data is intrinsically linked to continuous differentiation. We can argue that extruding or weaving material guided by an industrial robot is, therefore, the physical representation of an analogue process. This leads to the possible emergence of fabrication errors within the manufacturing process which require specific solutions that generally follow irregular patterns. A purely "digital" process would feature a discrete number of building elements and connection possibilities, leading to a limited set of information that would ease the creation of automated workflows.

The research presented in this article focuses on the design methods based on discreteness that aim to establish the frameworks for a purely "digital" architecture from design to fabrication. This approach leads to a series of projects in which building blocks are conceived for their robotic assembly into a large variety of structures. These projects are developed in a research-through-teaching context in the Bartlett Architectural Design (AD) Research Cluster 4 (RC4). AD is a part of BPro, an umbrella of post-graduate programmes in architecture at the Bartlett School of Architecture at University College London. The research, started in 2013, is led by Manuel Jiménez García, Gilles Retsin, and Vicente Soler. The student work is set within the framework of Design Computation Lab, which the three authors co-direct with Mollie Claypool.

INT

INT (Zoey Hwee Ting Tan, Xiaolin Yin, Qianyi Li, and Claudia Tanskanen, 2016) uses a discrete approach to introduce complexity in prefabrication. The team proposes timber blocks as basic building elements which could be robotically assembled into large-scale structures. An industrial robot is equipped with a gripper which could pick and place these elements into place. The geometry of the blocks is defined by the slots needed for gripping these elements in order to differentiate the combinatorial process. The application is based on a button-up approach, in which a flexible number of identical elements of two different scales combine together to fill a given volume. In the first stage, this 'basic mass' is analysed with Finite Element Analysis performed in Grasshopper Karamba. When imported into the framework, the force-flow and stress values influence the rotation of the pieces, limiting the possible connection to the satisfactory level of surface area between pieces. In the areas of a design that require more strength, the ratio of blocks with high surface area overlap is much larger. Blocks can be added or deleted according to variables such as cost or assembly time.

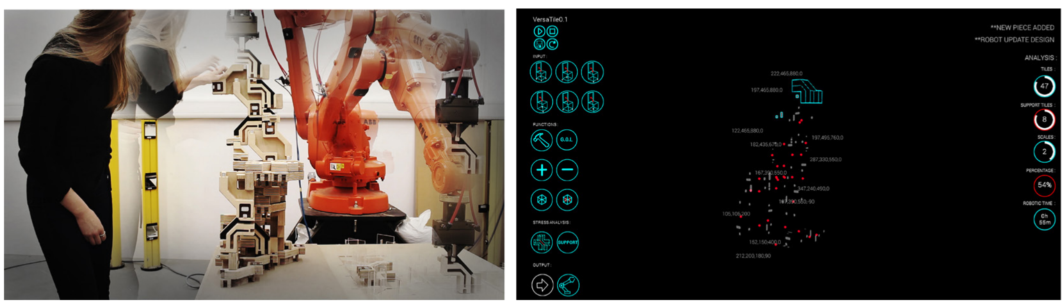

FIGURE 1 Interaction with the robot: The entire system can be recalibrate itself when elements are added or deleted either physically or digitally.

The blocks are equipped with integrated markers. These are read by an OptiTrack system that creates a digital version of each block in a virtual space. This setup facilitates the real-time update of the digital model while the assembly process takes place. This parallel between the digital and physical realm leads to a more direct interaction with robots since the entire system can recalibrate itself when elements are added or deleted either physically or digitally. To further ease the correction of errors while the assembly process takes place, this feature also allows the introduction of design changes at any given time.

The combinatorial algorithm used for this project allows the creation of infinite variations of structures. To prove the viability of the workflow, two chairs and one prototypical column were robotically fabricated. The chairs show two different degrees of human involvement in the design process. The first one is algorithmically created without human input, purely based on optimisation, while the second prototype is authored by the students and shows different pattern combinations with a symmetrical bias and a 2.3m column prototype, which aims to address architectural and structural requirements on a larger scale. Although the combinatorial algorithm and the pick and place system proved to be successful, the connectivity between the building blocks could be further improved to allow not only the assembly of these structures, but also their reconfigurability.

Transfoamer

Transfoamer (Gefan Shao, Na Wei, Ran Chen, and Zhilin Chen, 2017) builds on Design Computation Lab's research on Discrete Robotic Assembly, introducing the utilisation of lightweight materials to ease the fabrication of larger structures. The project aims to achieve high efficiency in robotic manufacturing by automating both the creation of the building blocks and their assembly.

A large block of high-density polystyrene foam is transformed into discrete blocks by an industrial ABB robot equipped with a custom-made hot-wire cutting end-effector. The building block is based on a tetrahedral grid, which allows an efficient packing of pieces in each polystyrene block to reduce material waste. Each building element is cut in three minutes, and later coated with polyurea, an elastomer derived from the reaction between an isocyanate and a synthetic resin-blend component through step-growth polymerisation. This increases the tensile strength of the pieces, as well as offering abrasion resistance and waterproofing. The coating also acts as a fire retardant.

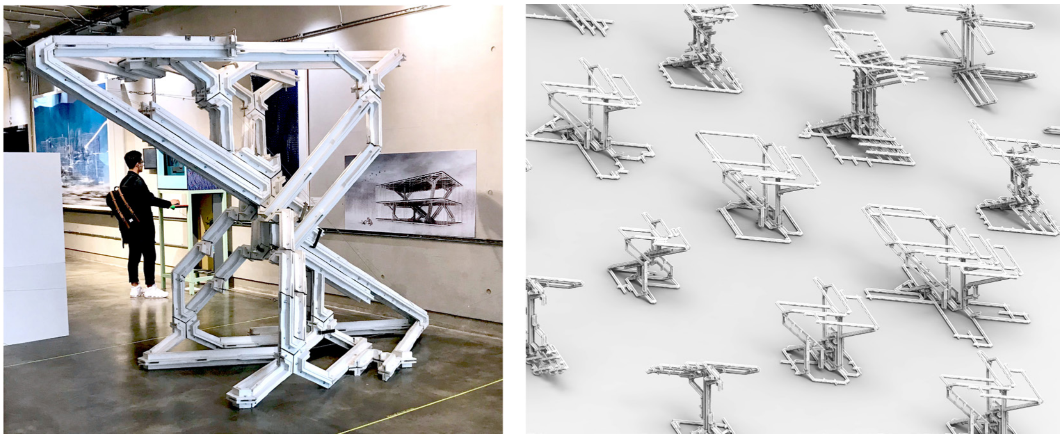

FIGURE 2 Combinatorial rules define number of rotations of the elements and respond to fabrication constraints and structural requirements.

In a subsequent step, an industrial robot assembles the blocks into larger chunks through the use of a vacuum gripper designed specifically for the geometry of the building elements. This process could also be produced by multiple robots working in tandem to reduce building time. The students developed an application using Unity that incorporates a computational logic to generate multiple design interactions. A set of combinatorial rules is applied to define a limited number of rotations of the elements and responds to fabrication constraints and structural requirements. For every possible combination, a probability factor is computed by relaxing the discrete optimisation problem into a continuous optimisation. Two topological methods – BESO (bidirectional evolutionary structural optimisation) and SIMO (solid isotropic microstructure with penalisation) – establish the guidelines driving the geometrical composition in the emergent structure.

The students produced a 3m x 3m x 3m prototype at the conclusion of this project, including 83 short tiles and 69 long ones. As in the INT project, an elongated component is added to the discrete set of pieces that allows spanning between structural nodes created by the smaller size pieces, as well as creating cantilevers.

Roblox

Roblox (Anna Uborevich-Borovskaya, Chenghan Yu, Hungda Chien, and Yen-Fen Huang, 2017) explores the use of combinatorial algorithms and robotic assembly at the scale of the built environment. The project is based on standardised UHPC (Ultra-High-Performance Concrete) building elements which can be assembled into large scale structures. They can be later disassembled and subsequently reconfigured into different formations, thus enabling flexibility and adaptability in construction that is missing from traditional prefabricated systems.

The team developed a building block which, as in the INT project, relates its shape to the grip of an industrial robot. The geometrical constraints to allow casting by using a laser-cut plywood reusable mould as well contribute to the formal definition of the building element. The initial element is generated from 7 regular triangles, connected into an L-shaped block. Its long side can be modularly extended into four different lengths. This allows the reduction of bending moments in those connections requiring structural continuity.

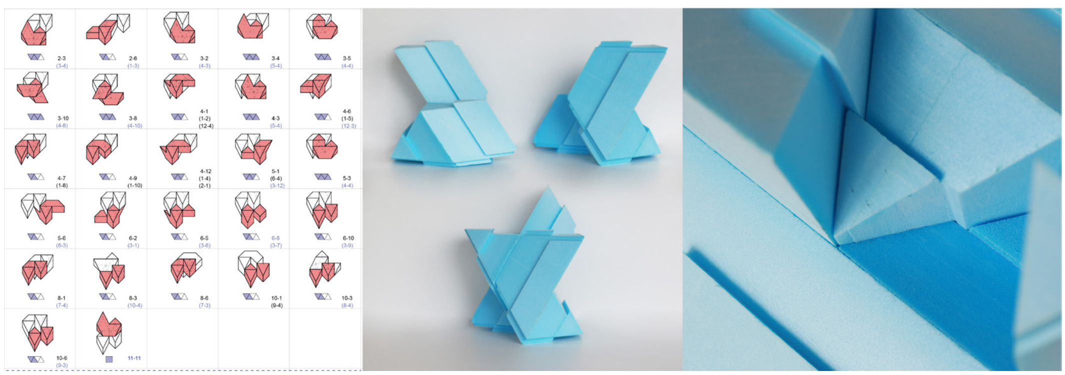

FIGURE 3 Combinatorial process generating stable structures.

To introduce reversibility in the assembly, the pieces are connected mechanically through triangular steel joints. As in other RC4 projects such as Transfoamer, the students built a custom application based on Unity which drives the combinatorial process towards stable structures. This software uses spatial rules and structural analysis as the main drivers for the combinatorial algorithm, calculating the type, position, and rotation of each piece in response to the main directions of stress, as well as ensuring the emergence of circulations and habitable space within the structure.

A plethora of pavilion-scale structures were created using this software. Under the sponsorship of LafargeHolcim, one of these structures was physically prototyped to demonstrate the viability of the system in construction. Rather than a closed shape, the built formation represents an open-ended construction system which could be extended into larger structures. The students digitally tested its potential, generating a 2-storey 14m x 8m x 7m housing prototype, not only using the UHPC blocks for the structural frame, but also extending the discrete design methods for the floor tiles and façade elements that feature clipping panels for their robotic assembly.

FIGURE 4 Physical prototype to demonstrate the viability of the system in construction.

Conclusions and Future Work

The projects featured in this paper demonstrate the potential of Discrete Robotic Assembly in architecture. Although it is still in its early stages, this research proves that there is an increase in construction efficiency in a discrete design framework. The research shows how a limited set of assembly possibilities eases the automation of the manufacturing process and leads to a reduction of labour, construction time, and cost. This intrinsic link between discrete design methods and automation hints at a potential shift in the construction industry governed by a new paradigm in computational design, where architectural elements are defined from and for automation.

RC4 research evolves more tectonically efficient methods in design and automation. While INT and Transfoamer focus primarily on the creation of different workflows in robotic fabrication, Roblox acknowledges the introduction of other architectural systems such as curtain walls and flooring. This demonstrates Design Computation Lab's research direction towards optimising construction through algorithmic design and fabrication.

The future development of this research includes a further investigation on hybrid systems that interface different materials with different tectonic purposes. In parallel, the lab aims to refine the models of interaction with robots in order to create not only a more economical and optimised construction framework through automation, but also to offer architectural values previously unexplored.

Acknowledgements

About Design Computation Lab:

Design Computation Lab is a new research laboratory at The Bartlett School of Architecture, University College London developing design methods for the utilisation of computational technologies in architectural design, fabrication, and assembly. The lab is directed by Mollie Claypool, Manuel Jimenez Garcia, Gilles Retsin, and Vicente Soler.

About RC4:

The Bartlett School of Architecture's BPro Research Cluster 4 (RC4), led by Manuel Jimenez Garcia, Gilles Retsin, and Vicente Soler, develops design methods for robotic fabrication. In previous years, RC4 has experimented with 3D printing, using industrial robots.

References

Gershenfeld, N., Carney, M., Jenett, B., Calisch, S., & Wilson, S. (2015). Macrofabrication with Digital Materials: Robotic Assembly. Architectural Design 85, no. 5: 122-127.

Schumacher, P. (2016). Parametricism 2.0: Rethinking Architecture's Agenda for the 21st Century AD. Hoboken: John Wiley & Sons.

www.spool.tudelft.nl

ISBN 978-94-6366-200-0