Robotically Driven Architectural Production

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Abstract
Robotically driven architectural production advances seamless, computer-numerically controlled (CNC) and robotically supported design to production and operation processes enabling implementation of robotically driven buildings from conceptualisation to use. It enables production of free-formed, heterogeneous, optimized structures in order to address specific requirements in terms of properties (density, consistency, rigidity, etc.) and behaviours (re-configurability, responsiveness, etc.) in accordance to formal, functional, structural, climatic, environmental, and economic needs. This may require multi-robot collaboration implying that several robots collaborate with each other and humans in the process of production and assembly of multi-material, free-formed, diverse, and optimized building components and buildings.

Keywords
Robotically driven architecture; robotically driven production; sensor-actuator mechanisms; cyber-physical systems.

Note
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Introduction

Architecture is increasingly incorporating sensor-actuator mechanisms that enable buildings to interact with their users and surroundings in real-time. These require design to production, assembly, and operation chains that may be (in part or as whole) cyber-physically or robotically driven. Development of concepts and practical applications for robotically driven architectural production, leading to the emergence of customizable, interactive building components that operate in ever-changing environments, requires an understanding of buildings from a life-cycle perspective with respect to their socio-economic and ecological impact. This paper presents design to operation experiments undertaken at Hyperbody TU Delft aiming at establishing modelling, simulation, and 1:1 prototyping frameworks that facilitate not only customization of tools, materials, and processes, but also collaboration and exchange between (natural and artificial) experts from different disciplines.

Robotically Driven Architecture

Robotically driven architecture, as explored within Hyperbody, comprises building components with embedded robotic devices. Such robotic building components exhibit behaviours that follow simple rules in order to satisfy structural, climatic, or spatial requirements and build collectively a dynamic, intelligent system. In order to achieve this systemic connectivity, components may be tagged and incorporate information regarding their design, structure, materialisation, production, assembly, and operation. Furthermore, they may be equipped with sensors and actuators that enable them to not only perceive but also act on their surrounding environment. This ability to act may imply physical -geometrical, material- or sensorial transformation and reconfiguration, whereas sensorial refers in this context to ambient properties.

In general terms, application of embedded robotics in architecture has been identified in areas dealing with (a) health, demographic change and well being, as well as (b) sustainable climate control and energy production. For each of these areas, robotics may be employed as follows:

Robotically driven building components may support daily life activities offering solutions for addressing rapid increase of population and urban densification as well as contempo-
The aim of robotically driven architecture is to address societal issues such as the current vacant office space (16%) in Netherlands by increasing up to 50-75% the 24/7 use of built space through changing and multiple uses in reduced timeframes. Furthermore, the increase of urban population from 3.2 billion to nearly 5 billion by 2030 with, according to UN, 3 out of 5 people living in cities may be successfully addressed by improving inefficient use of built space (25%) through spatial reconfiguration. Last but not least, the advancement of embedded, interactive or robotic, energy and climate control systems employing renewable energy sources such as solar and wind power are aiming at reducing architecture’s ecological footprint while enabling energy efficient and demand-driven use of space. In this context, robotically driven architecture establishes a framework for investigating applications of robotics to responsive, adaptive, and reconfigurable architecture.
Reconfigurable, robotically driven environments incorporating digital control, namely sensor-actuator mechanisms that enable buildings to interact with their users and surroundings in real-time\textsuperscript{3,4}, through physical or ambiental change and variation, require multi-disciplinary research. Focal points of this research are the architectural design and engineering of reconfigurable, robotic systems employing horizontal and vertical spatial expansion based on additive-subtractive and folding principles, the materialisation research for rapid computer-numerically controlled (CNC) or robotic fabrication and assembly as well as sustainable operation in-situ. In this context, robotically driven architecture is envisioned as a modular\textsuperscript{5}, bendable or foldable\textsuperscript{6} by spatial motion (kinematics) self-adjustable and self-assembling system.

Robotically driven architecture builds upon knowledge in non-standard and interactive architecture developed at Hyperbody in the last decade [Figure 2] and has been explored with MSc 4 students (2012) as adaptive systems embedded into public buildings [Figure 1] and further prototypically developed with MSc 2 students (2013) as reconfigurable, multimodal apartments. Furthermore, indoor climate regulating systems were explored with MSc 1 and 3 students (2013-14). While the multimodal apartment (http://multimod.hyperbody.nl) has proven, as in case of the Pop-up apartment [Figure 3] that spatial reconfiguration can optimize 24/7 use of built space, the climate control related investigation has shown that integrating distributed interactive climate control devices into building components may contribute considerably to improving indoor climate.

Considering that the aim of the multimodal apartment was to design a small apartment of 50m\textsuperscript{2} that has all spatial qualities and functional performances of a standard 100m\textsuperscript{2} apartment, the initial assumption was that when a user is in the living room, this user does not use the sleeping room at the same time implying that at one moment in time large sections of the space could cater to only 1-2 functions. Basic recommendations for the design were inter al. to use of dry assembly, use scripting (the designed structures is

\begin{figure}
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\includegraphics[width=\textwidth]{figure3.jpg}
\caption{Reconfigurable apartment developed by Hyperbody with MSc 2 students and industry partners (Pop-up Apartment, 2013)}
\end{figure}
generated and handled through scripted algorithms) and CNC fabrication, as well as use of Design Information Models (DIM) to establish efficient design to operation chains. The proof of concept implied building 1:1 prototypes, which in case of the Pop-up apartment [Figure 3] shows that spatial subdivision and furniture reconfiguration exploiting material and geometrical properties easily facilitate 24/7 change of use.

**Robotically Driven Design to Operation Processes**

Robotically driven design to operation processes exploit CNC and robotic means in order to establish a feedback loop between conceptualisation, production, and use. Explorations with robotic fabrication have been implemented more recently with two large ABB robots, which were customized to perform specific tasks by employing specialized operating tools and programs. A series of experiments were implemented with MSc 2 students in order to develop and test robotic fabrication methods by establishing a feedback loop between design and fabrication. The assumption was that by employing robotic fabrication, customized designs could be easily implemented so that users may change (extend, reduce, expand, shrink, etc.) built environments on demand.

Such explorations with robotic fabrication indicate that architectural production becomes procedural instead of object-oriented and form emerges from a process in which the interaction between all (human and non-human) parts of the system generates the result.

**Conclusion**

Research and experimental developments in interactive building implemented at Hyperbody in the last decade such as Interactive Wall (http://www.hyperbody.nl/research/projects/interactivewall/) and more recently Interactive Skin [Figure 1] employing multiple and distributed sensor-actuators integrated into architectural components confirm that distributed intelligent control is a viable option for addressing contemporary needs for reconfiguration and demand-driven use of physically built environments. The advancement of such environments requires further research into the integration of intelligent devices into multi-functional building components in order to ensure not only physical reconfiguration but also climate control and energy management in accordance to user’s needs, indoor-outdoor environmental conditions, and availability of conventional and non-conventional energy sources within the larger energy framework is a more recent preoccupation.
In principle, the goal of robotically driven architectural production is to further advance seamless, computer-numerically controlled (CNC) and robotically supported design to production and operation processes enabling implementation of robotically driven buildings from conceptualisation to use. Robotically driven building is the focus of research at Hyperbody largely due to its ability to generate on-demand and on-site produced, customized buildings and building components. In this context, Hyperbody aims to investigate the potential of robotic building by exploring multi-material robotic construction enabling production of free-formed, heterogeneous, optimized structures in order to address specific density, consistency, rigidity, etc. requirements in accordance to formal, functional, structural, climatic, environmental, and economic needs. This requires multi-robot collaboration implying that several robots collaborate with each other and humans in the process of production and assembly of multi-material, free-formed, diverse, and optimized building components and buildings.

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References


