



Parametric design strategies: robotic building in academic architectural research and education

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How to quote this text: Bier, H. Parametric design strategies: Robotic building in academic architectural research and education. *VIRUS*, 11. [e-journal] Available at: <<http://www.nomads.usp.br/virus/virus11/?sec=5>> [Accessed dd mm yyyy].

Henriette H. Bier is a lecturer and researcher at TU Delft, Netherlands. She currently coordinates projects and workshop series and lectures about design and digital fabrication in DSD (Delft School of Design). Her research focuses not only on analysis and critical assessment of digital technologies in architecture, but also reflects evaluation and classification of digitally-driven architectures through procedural and object-oriented studies.

ABSTRACT

Parametric design strategies employing design-to-robotic-production (D2RP) approaches are relative new in architecture. They require trans-disciplinary research that at Hyperbody, TUD is experimentally tested in academic education and research. This paper presents and discusses trans-disciplinary approaches employing strategies that cross several disciplinary boundaries such as architectural design, structural engineering, material sciences, and robotics in order to create a holistic approach.

KEYWORDS

parametrization, V!11, robotic, digital fabrication.

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1. INTRODUCTION

Robotic Building (RB) implies both physically built robotic environments and robotically supported building processes. Physically built robotic environments consist of reconfigurable, adaptive systems incorporating sensor-actuator mechanisms that enable buildings to interact with their users and surroundings in real-time. These require design-to-production (D2P) and operation chains that may be (partially or completely) robotically driven. RB, therefore, offers solutions for energy-efficient building, demand-driven production and operation, and efficient use of resources.

RB advances expertise in Non-standard and Interactive Architecture (NS&IA) developed in the last decade at Hyperbody, TU Delft and has been conceptually developed as independent research strand since 2009. It builds up on research in system-embedded intelligence (Bier, 2008), which has been further advanced with focus on robotic systems. It relies on the integration of robotic or cyber-physical and cloud-computing technologies into architectural production and operation, which leads to new approaches (Wu, Rosen and Schaefer, 2014) that are exploiting technologies of the 4th industrial revolution. If the 1st industrial revolution originated from the mechanization of production using steam power, and it was followed by the 2nd industrial revolution, which introduced mass production employing electric power, the 3rd digital revolution, made use of electronics to automate production (inter al. Brünglinghaus, 2015). The 4th industrial revolution implies the use of cyber-physical or robotic systems and the Internet of things and services in order to monitor physical processes by creating virtual representations of the physical world that support decentralized decisions making (inter al. Kagermann, et al., 2013).

RB relies, therefore, on (a) interoperability, which is the ability of robotic systems, humans, and factories to connect and communicate via the Internet of things and services, (b) virtual-physical coupling by linking sensor-actuator data (from monitoring physical processes) with virtual models and simulations, (c) decentralization, which is exploiting the ability of robots to operate autonomously, and (d) real-time operation implying that data is exchanged in real-time (inter al. Hermann, Petek and Otto, 2015; Oosterhuis and Bier, 2013). RB employs all these concepts and extends them by including in the D2P loop the actual operation of buildings.

This paper presents and discusses implementation of RB in education and research with respect to trans-disciplinary approach ensuring transfer of knowledge from one discipline to another. The main disciplines involved are architecture, structural engineering, material sciences and robotics. Within these disciplines, specific aspects such as parametric design, programming, sensing, actuating and control systems, etc. are interfaced in order to develop strategies that cross disciplinary boundaries in order to create a holistic approach.

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Figure 1: Reconfigurable apartment developed by Hyperbody with MSc 2 students (MultiMod, 2013).

2. DESCRIPTION

The RB concept is based on understanding and conceiving buildings from a life-cycle perspective with respect to their cultural, socio-economical, and ecological impact. The assumption is that robotic building components may offer solutions for dealing with the rapid increase of population and urban densification, as well as the contemporary inefficient use (25-50%) of built space by introducing spatial reconfiguration, which is enabling multiple, changing uses within reduced timeframes. Furthermore, embedded, interactive or robotic energy and climate control systems may reduce architecture's ecological footprint while enabling an energy-efficient, time-based, and demand-driven use of space. Such robotic systems rely on D2P and operation processes that are connecting parametric models with numerically controlled (NC) and robotised fabrication in order to achieve efficient production and operation of customized components for personalized use.

3. RESEARCH

RB addresses to two **paradigm shifts** implying (a) a transition from mechanical, industrial production to NC and robotically driven mass-customization and (b) a move from inanimate (inert, insentient) to animate (actuated, sentient) architectural environments. RB employs cyber-physical or robotic systems and the Internet of things and services in order to monitor physical processes by creating virtual representations of the physical world that support decentralized decisions making (Kagermann, et al., 2013; Bier and Mostafavi, 2015). This is relevant because of its impact on architecture with respect to energy-efficient building, demand-driven production and operation, and efficient use of resources.

Two research strands are addressing the two paradigm shifts: (3.1) Design-to-Robotic-Production and Operation Processes and (3.2) Robotic Building Components.



Figure 2: Hyperbody MSc 4 project featuring interactive building skin components employed for ventilation purposes.

3.1. DESIGN-TO-ROBOTIC-PRODUCTION AND OPERATION PROCESSES

RB processes link design to materialization by integrating all functionalities (from structural strength, to thermal insulation and climate control) in the design of building components. This is implemented by employing novel **multi-performative** D2P strategies: New materials are developed for the robotic production of **multi-material** building components and novel robotic production and assembly tools are deployed for testing the blueprint of future robotic building.

The main consideration is that in architecture and building construction the factory of the future employs building materials and components that can be robotically processed and assembled. RB processes employs customized D2P loops that incorporate material properties in design, control all aspects of the D2P process numerically, and utilizes parametric design principles that can be linked to the robotic production.

This framework exploits expert and user involvement challenging the production-consumption gap by connecting parametric models with robotized production tools in order to achieve efficient production of custom-made parts for personalized use.

First experiments such as Scalable Porosity (fig. 3-6) and Continuous Variation have been focusing on several aspects: (a) Robotic production of porous structures (<http://m4h.hyperbody.nl/index.php/Msc3G4:Group>) with material deposited only where needed and (b) multi-tools and -modes robotic techniques allowing for developing hybrid components consisting of various materials.

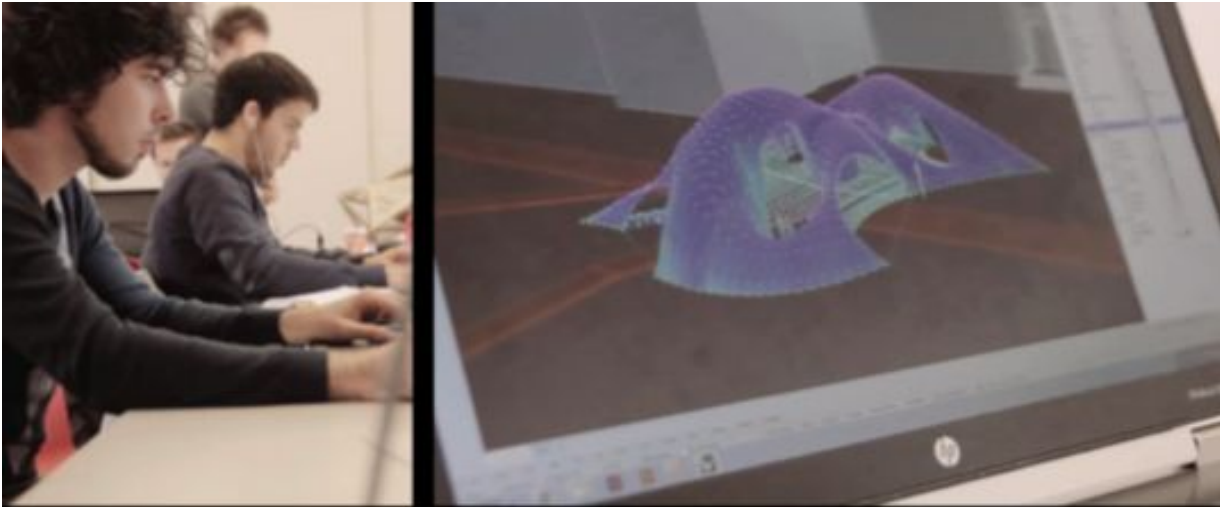


Figure 3. 3D modelling and structural simulation for a piece of urban furniture developed with MSc 3 students (Hyperbody, 2014).

3.2. ROBOTIC BUILDING COMPONENTS

The development of building components incorporating robotic devices ensures physical or sensorial spatial reconfiguration that responds to and extends human needs. Experiments such as Multimodal Apartment and MyClimate investigate the potential of in building components embedded robotics for use-and energy-efficiency of built space.

The Multimodal Apartment experiments (<http://multimod.hyperbody.nl>) have proven, as in case of the Pop-up Apartment (fig. 1), that spatial reconfiguration can optimize 24/7 use of built space, while the climate control related investigation has shown that integrating distributed interactive climate control devices into building components may contribute considerably to improving indoor climate and reduce energy consumption.

MyClimate as indicated in the Climate-Skin (fig. 2) aims to implement distributed, in building components-embedded, intelligent climate control, whereas control is performed by wirelessly networked climatic components that are locally driven by users' preferences and indoor-outdoor environmental conditions. In such context, climate control components communicate wirelessly and intelligently not only with each other but also with all (other) building components, inhabitants and indoor-outdoor environment in order to provide healthy indoor climates and ensure energy-efficient use. While climates may differ depending on local needs and demands from space-to-space or even place-to-place, a variety of climate characters is ensured within the larger framework of a building.

The two research strands complement each other, as reconfigurable spaces require D2P processes that allow the modelling, simulation, and prototyping of such architecture.

RB research and academic education related activities inform each other with the aim to exploit synergy effects and valorise research results by on the one hand introducing new design-to-production (D2P) methods to future architects and on the other hand by involving industry partners in research projects.

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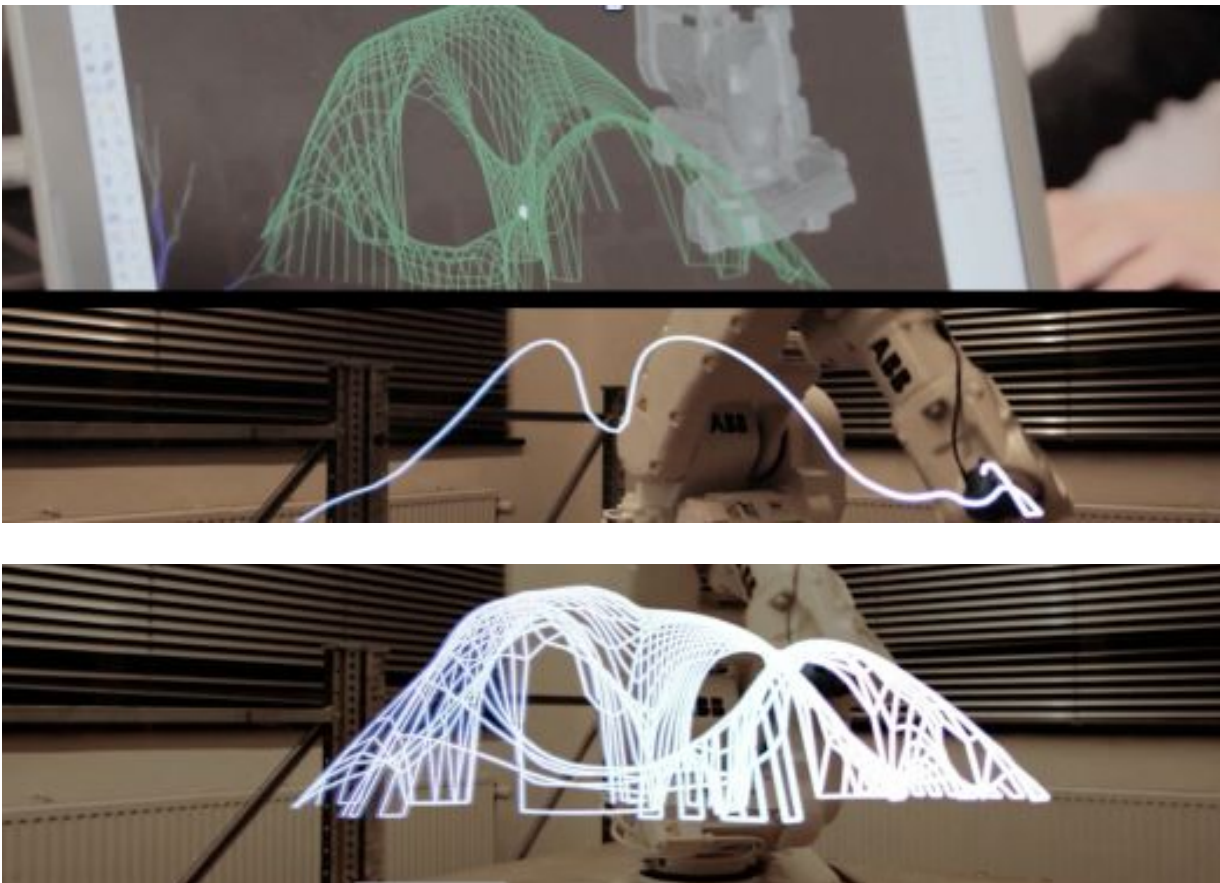


Figure 4. Robotic light experiments exploring path definition for the 3D model (Hyperbody, 2014).

4. EDUCATION

RB research is experimentally tested with MSc students with the aim that students develop knowledge, skills and competencies in architectural design satisfying aesthetic, technical and functional requirements. During the MSc 1-4 trajectory the complexity of the architectural design increases leading to the level required in the contemporary architectural practice. RB introduces students to the impact of the 3rd and 4th industrial revolutions on architecture and knowledge is developed with respect to architectural design, material sciences, structural engineering, and robotics. Additionally, skills are acquired to develop an understanding of the design process in relationship to the socio-economical, and cultural context aiming to address **societal urgencies** such as rapid urban densification, inefficient production and use of physically built space, material depletion, and environmental pollution. Knowledge, skills, and competencies are developed not only with regard to content but also methods of investigation, reflection, and design. Furthermore, skills are acquired to incorporate an understanding for the design process with regard to structural design, materialization, and climate control.

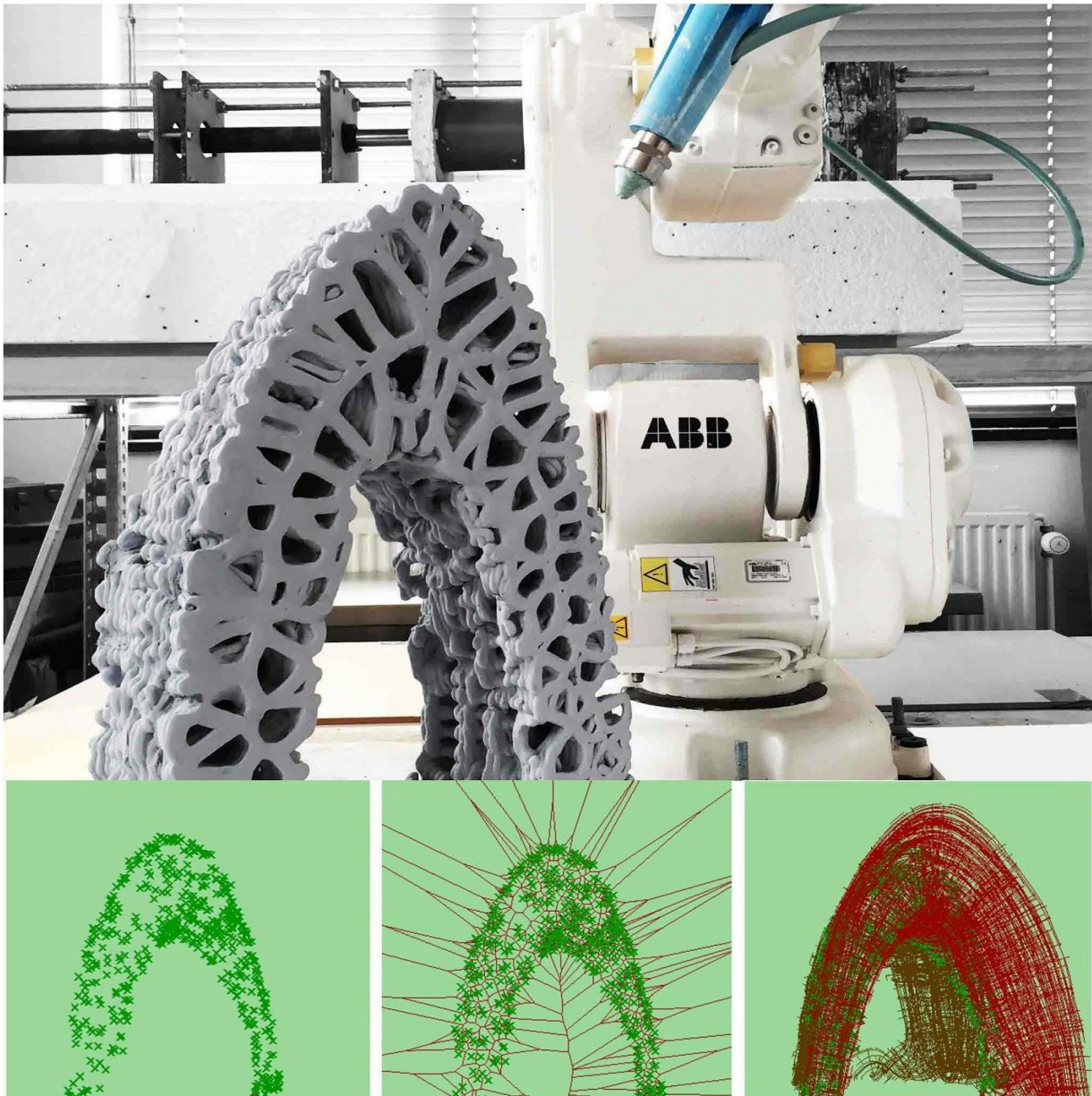


Figure 5. Fragment of urban furniture (1:1 scale) structurally optimized and robotically 3D printed at Hyperbody (2015).

Intellectual work (research, reasoning, interpretation) is implemented with the aim to integrate specific RB knowledge into the broader field of architectural expertise. Exposure to different even conflicting positions in the contemporary architectural discourse and problem-based learning enables students to develop and use theories, models and interpretations, exert critical reasoning and form judgments while taking into account the temporal and societal context. By establishing a strong relationship between **theory and practice** students understand the implications and significance of trans-disciplinary approaches in architecture.

5. OUTLOOK

The next step is to on the one hand consolidate achieved developments and on the other hand expand and advance by introducing RB **online education and research** as it represents a relevant alternative platform for studying and researching by connecting virtually students,

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researchers, and educators from all over the world.

Furthermore, RB aims to further investigate the potential of NC and robotic building processes in order to achieve generation of material-efficient, cost-effective, on-demand produced, customized building components and buildings. In particular two aspects will be explored:

(5.1) Multi-material robotic construction enabling production of free-formed, heterogeneous, optimized structures by additively and selectively depositing materials in order to achieve specific porosity/density, flexibility/rigidity, etc. requirements in accordance to formal, functional, structural, climatic, environmental, and economic needs;

(5.2) Multi-robot production implying that several robots operate simultaneously or in short sequence in the process of production and assembly of multi-material building components. This is necessary in order to, for instance, deposit reinforcement fibers or granular insulation material, etc. in parallel to depositing cement-based materials, etc.

2015-20 this research will aim for implementation at **multiple scales** (from building component to building level) with **multiple robots** by employing a **trans-disciplinary approach** that is **connecting academic research with not only education but also with practice** and is bringing building production to the next level.

ACKNOWLEDGMENTS

This paper has profited from the input of Hyperbody and Robotic Building teams. Robotic Building (RB) projects have been supported 2014-15 by 3TU, Delft Robotics Institute (DRI), 100% Research, AE&T, ABB and KUKA.

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