Kite-Powered Design-to-Robotic-Production for Affordable Building on Demand

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Abstract –

Building technologies employed today in 2nd and 3rd world countries are imported, expensive, outdated and unsustainable. Highly developed countries, on the other hand, rapidly advance in developing affordable, numerically controlled and robotically supported material- and energy-efficient methods for building on demand. The research team proposes to close this gap by applying advanced design-to-robotic-production (D2RP) technologies developed at Technical University Delft (TUD) to construction problems in 2nd and 3rd world countries. The provided tool base uses refurbished robotic technology, which is retrofitted with state-of-the-art open source control software, and by employing local approaches and available materials the dependency on imported materials and processes is drastically reduced. The D2RP unit is coupled with the electricity generating Kite Power (KP) system developed at TUD to create a mobile sustainable autarkic unit that can be deployed everywhere.

Keywords –

Robotic building, material- and energy-efficient building, building on demand, autarkic Design-to-Robotic-Production, kite power system

1 Introduction

The societal challenge that the kite-powered robotic building system aims to solve is building affordable, material- and energy-efficient housing with Design-to-Robotic-Production (D2RP) methods powered by sustainable Kite Power (KP). It is important to tackle this challenge now because in the developing world 900 million people live in slums [1] and technology developed at Technical University Delft (TUD) allows to address this.

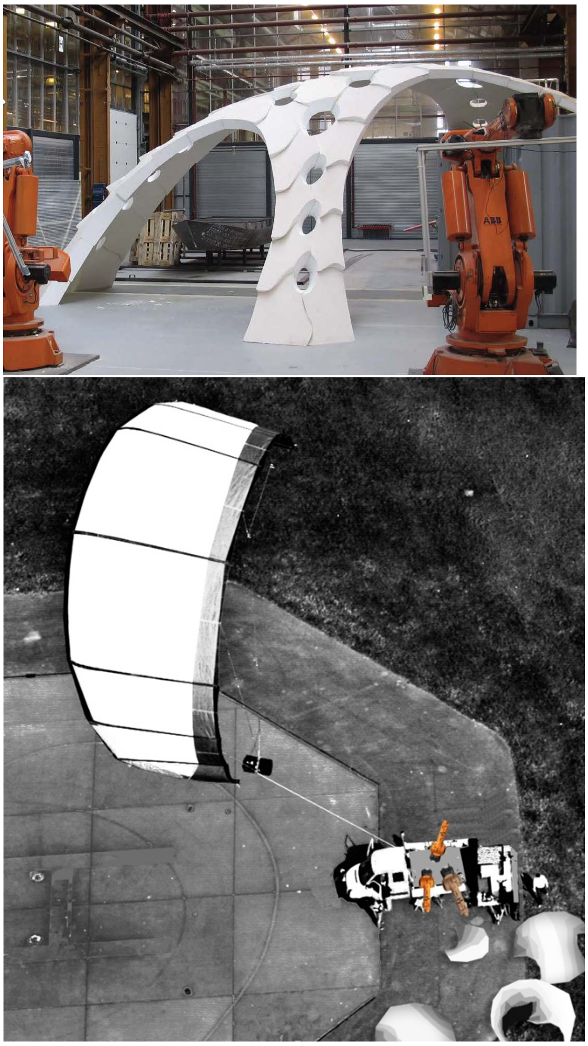

Figure 1. From laboratory to relevant environment - Impression of how D2RP could be moved from laboratory (top) to operation in situ and together with KP system (bottom) to produce affordable housing units

The kite-powered robotic building system aims to develop and deploy a mobile autarkic robotic building system for affordable, material- and energy-efficient housing in 2nd and 3rd world countries. Main objective is to counteract poor housing conditions and increasing economic migration by offering strategies for affordable housing and economic growth through, material and energy-efficient building by deploying sustainable robotic processes in situ. The assumption is that D2RP technologies counter negative effects of globalization and maximize the role of local human resources and construction materials by using new, customizable, open-source procedures, inspired by autochthon building approaches. The strategy is to develop and provide necessary D2RP and KP system knowledge and application know-how. Equipment to enable local implementation consists of a set of computational and robotic tools such as recycled computers (with Linux OS) and scrap robots (similar to the ones shown in fig. 1).

2 Description

D2RP together with the KP system developed at TUD allows for ad hoc set-up and operation anytime and everywhere with minimal infrastructure. It is based on a generic methodology relying on a robust, scalable, yet highly flexible technology. The assumption is that when such customizable fabrication set-up is provided to users in order to address local needs and conditions, users can easily customize processes employing local materials and parametric designs. The aim is to develop methods derived from the study of local resources and approaches by customizing materials and employing parametric design and robotic fabrication.

TUD has been developing knowledge on how to connect and deploy D2RP with KP, customize the D2RP system and will (experimentally) implement proof of concept by testing mobile D2RP system at Valkenburg airbase and on TUD campus in Netherlands in 2017. While the D2RP system developed at TUD is addressing challenges of next generation building [2] it can also be applied to local conditions in 2nd and 3rd world countries by employing local materials, inspired by autochthon building approaches. By researching an array of techniques exploiting local materials and techniques the focus may shift towards weaving (with local fibers but also if applicable synthetic fibers coming from waste), local clay-based production methods, rock/soil- and wood-processing approaches. If until now the team has explored additive and subtractive techniques with ceramic clay and polymers, respectively in laboratory environment, the next step is focusing on exploring possibilities for off the grid production in situ with KP energy.

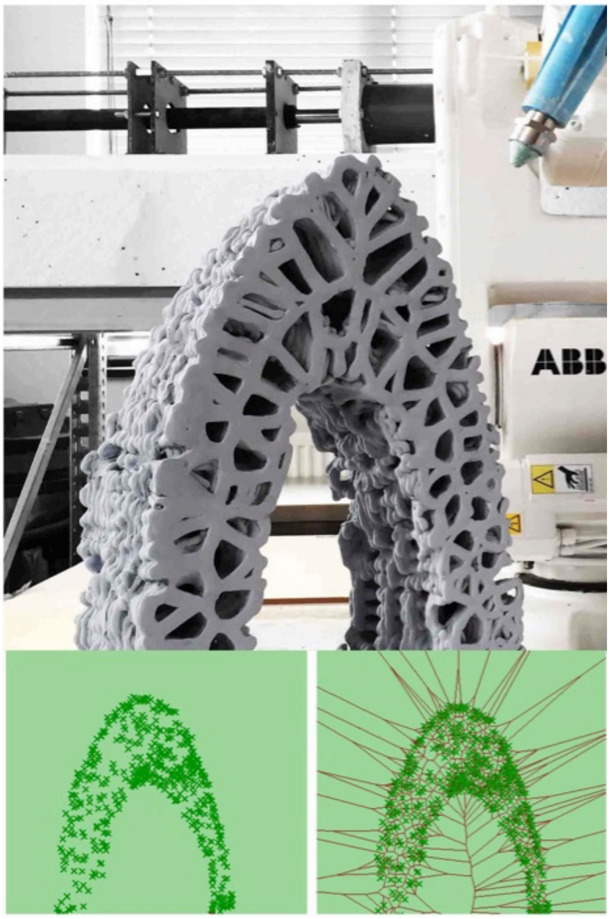

Figure 2. Building component (1:1 scale) structurally optimized and robotically 3D printed (BK-TUD, 2015).

2.1 Design-to-Robotic-Production (D2RP)

The D2RP system developed at TUD consists of a robotic arm with a changeable end effector or tool, robot motion tool path component, a parametric digital model, micro-controller and robot controller units (fig. 2). The system allows linking the design to the production process (Bier, 2014; Bier and Mostafavi, 2015) and is highly customizable. By employing approaches involving multi-tools, -materials, and -robots the D2RP system establishes a platform for building on demand.

Explorations in robotic building implying numerically controlled (NC) and robotically supported design to production chains, have been implemented since 2012 at Hyperbody, TUD first with two large refurbished ABB robots (fig. 1), which were customized to perform tasks with specialized operating tools and programs [3]. Since then, a series of experiments were implemented 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 end-users may be easily able to transform (extend, shrink, expand, etc.) physically built environments on demand.

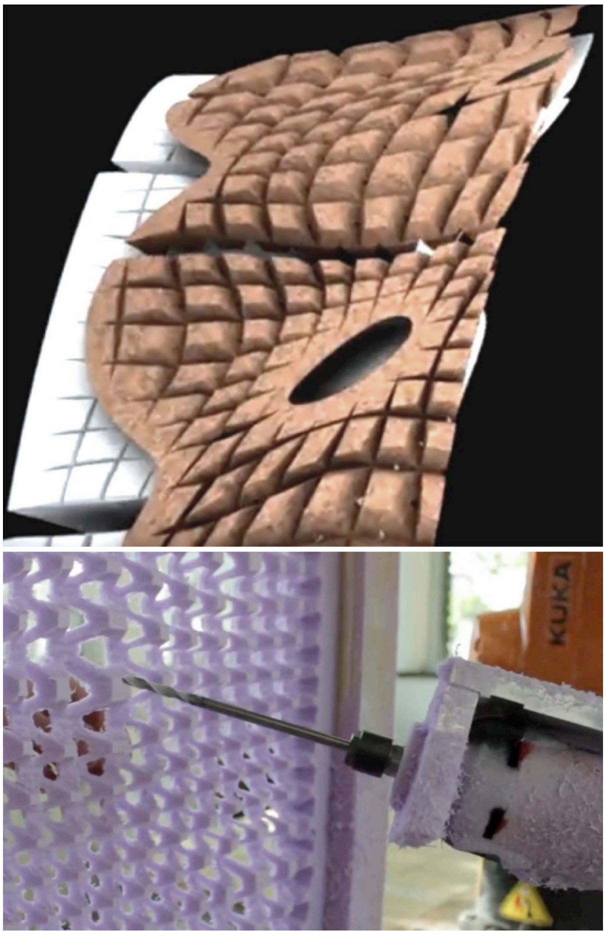

Figure 3. The behavior of polymer- cork-based materials is manipulated from rigid to flexible by means of 3D subtractive techniques.

Initial experiments with robotic subtractive manufacturing (fig. 1&3) where followed up by additive robotic production (fig. 2), which implied linking design to materialization by integrating all functionalities (from structural strength, to thermal insulation and climate control) in the design of building components. These experiments proved that D2RP processes enable production of free-formed, heterogeneous, optimized structures by additively and selectively depositing or manipulating materials [5] in order to achieve specific porosity-density, flexibility-rigidity, etc. requirements in accordance to formal, functional, structural, climatic, environmental, and economic needs. In fact, D2RP requires 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 or ceramic materials, etc.

The D2RP system is ready to be utilized in combination with the KP; however, D2RP experiments have only been implemented in laboratory environment. These experiments have shown that D2RP contributes to the reduction of economical inefficiency and environmental damage mainly because its processes establish a direct link between conceptualization, design, engineering, fabrication and operation of buildings. Furthermore, increased material and energy efficiency is achieved through structurally and climatically informed material distribution.

The obvious advantage is that the system is versatile as it can operate a large range of tools and can manipulate material from all sides 24/7. The operation outdoors is constrained due to weather conditions and requires consideration with respect to wind forces having an impact on the operation of the system. Also, use of local materials requires adaption of the system and tools to respective requirements.

2.2 Kite Power (KP)

KP system developed at TUD is based on an inflatable wing operated in periodic pumping cycles (fig. 1 and 4). The wing is steered by a kite control unit (KCU) suspended below the wing (fig. 4). The KCU receives the steering commands from the control center at the ground station via a wireless connection (one link for nominal operation plus two backup links). This wireless connection is also used to stream sensor data down to the ground control. The traction force of the kite is transferred to the ground station by a single tether. The nominal altitude limit is 500 m, however, the technology allows operation beyond 1 km altitude [6].

Kite Power is a cost effective renewable energy solution [7] with a low environmental footprint. It is an ideal basis for a highly mobile wind energy system. The heavy generator is positioned at ground level, which facilitates servicing and also minimizes structural forces. The direct force transmission into the ground station removes the need for bending-resistant foundations, which facilitates deployment. The technology demonstrator uses a tele-operated airborne unit, which can access altitudes far beyond the limit of conventional wind turbines (200 m). Wind at these altitudes is stronger and steadier which increases capacity factors of the system to about 60%. Conventional wind turbines presently achieve values of 20-35%.

The system is operated in periodic pumping cycles, alternating between reel-out and reel-in of the tether. During the reel-out the kite is flying figure eight maneuvers at high speed (70-90 km/h). This creates a high traction force (3.1 kN at 7 m/s wind speed), which is converted into electricity by the drum and the connected 20 kW generator (fig. 5). When reaching the maximum tether length, the kite is de-powered by releasing the rear (steering) lines such that the whole wing rotates and aligns with the wind.

Figure 4. Kite Control Unit and bridle system during launch (Photo: Max Dereta)

Using the drum/generator module as a winch, the kite is then pulled back to the initial position to start the next pumping cycle. De-powering reduces the traction force during reel-in by 80% and for this reason the energy consumed during reel-in is only a fraction of the energy generated during reel-out. Crucial element of the technology is the automatic control and synchronization of the drum/generator module and the flight dynamics of the kite.

2.3 Kite-Powered D2RP

By connecting D2RP with KP, the system becomes mobile and autarkic. The proof of concept will be implemented by testing the mobile, kite-powered D2RP system at Valkenburg airbase and on TUD Green Village campus in Netherlands. While the KP system has been outdoors tested for 2 years now the move of the D2RP system from laboratory to outdoors is unprecedented. This is especially challenging because of the rather unpredictable nature of the environment with respect to terrain and weather conditions. Inconstant operational characteristics caused by environmental influences such as temperature, rain, and wind may require recalibration of the robot and its tools. Starting with experiments involving one robot, the project will evolve towards exploring multi-material and -robots techniques that are required for the implementation of all construction related tasks.

Another aspect that needs consideration is power supply: Medium sized industrial robots operate using single phase AC of 220-230V at 50Hz while larger robots require a stronger, three phase AC supply of 400V at 50Hz. Given these functional and technical specifications, a storage and conversion solution for the electricity produced by KP is currently being investigated, while AC power stabilizers for both lower and higher voltages are being considered. The research team proposes a DC link connection at 400V for small robot arms, respectively 600V for medium-large robotic arms. This enables the robotic system to function on the DC output of Kite Power avoiding costly DC/AC AC/DC conversion. The D2RP-KP connection will be enabled via a combination of Lithium batteries that provide operation energy for a couple of hours and Ultracapacitors that supply energy during load or generation peaks. The conversion and stabilization issue for KP-produced electricity is important especially as the research team considers the implementation of multi-robotic D2RP required for executing a variety of complex building operations.

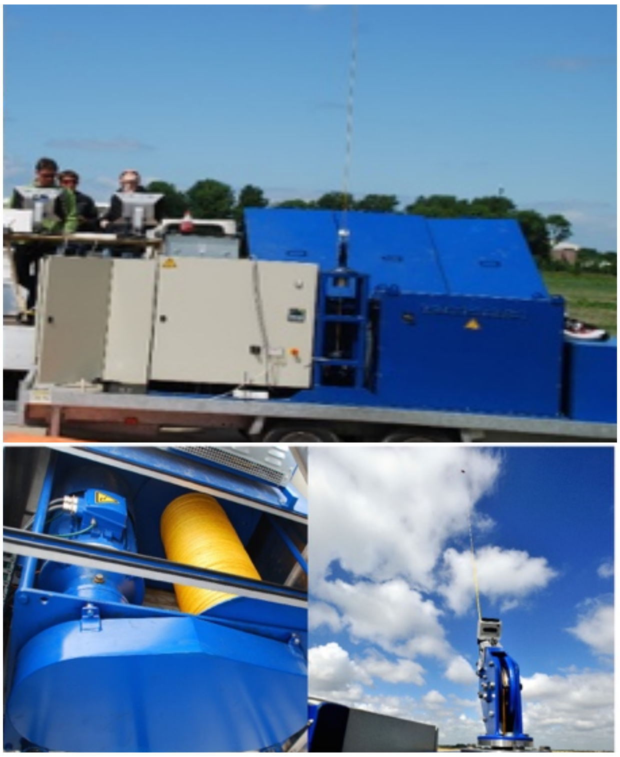

Figure 5. Ground station on trailer with tether running into the sky (top), swivel with video camera mounted and tether running into the sky (bottom right) and drum/generator module mounted on transverse sled (bottom left)

3 Conclusion

The kite-powered robotic building system will contribute solving current housing problems by connecting kite-powered robust and highly reliable industrial robotic technologies with local production approaches. This will lead to the development of products and processes for local building markets providing both sustainable means of habitation as well as new job opportunities in the field of KP D2RP. This is directly relevant to communities in terms of providing affordable healthier living environments and creating impulse for economic activity with low-cost, easy-to-operate tools.

Considering that KP D2RP methods cut production costs more than 40% and delivery times to 100%, while additional savings are achieved by increasing material and energy efficiency, this research presents an approach to affordable housing that can be applied anytime everywhere. The kite-powered robotic building system allows for ad hoc set-up and operation with minimal infrastructure. The assumption is that when such customizable fabrication set-up is provided to communities in order to address local needs and conditions, users can easily customize processes employing local materials and parametric designs.

Acknowledgements

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