participants are taken on board by the authorities.

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WORK IN PROGRESS

EMERGENT CONSTRUCTIONS:

EXPERIMENTS TOWARD GENERATIVE ON-SITE DESIGN AND BUILD STRATEGIES USING CUSTOMIZED DIGITAL DEVICES

ABSTRACT

This paper presents ongoing research investigating integrated design-and-build workflows using generative design strategies and custom-built fabrication devices.

The aim of the research, which is being developed through a series of experiments and workshops, is to explore scenarios in which these workflows can produce emergent architectural structures that are highly adapted toward the intended performance within their specific context and site.

The research has produced a number of installations and prototypical structures that test the practical and theoretical dimensions of the methodology explored. It introduces intriguing new scenarios in which the architect's role is focused on an indirect control of the process of design, allowing for a more open-ended method of negotiation between structure, users, and environment.

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1 INTRODUCTION

The work presented in this paper explores the opportunities emerging around the direct coupling of digital design tools and numerically controlled fabrication devices. Architectural practice and academia have enthusiastically embraced these opportunities to construct formal complexity, yet have been slow to speculate on how these new technologies could alter the nature of the design-build process itself. Our work explores new scenarios for the conception and construction of architectural structures, investigating how design methods could allow for the integration of additional qualities that are described through criteria of performance instead of form. It proposes new roles for digital fabrication equipment, focusing on devices that are relatively simple and custom designed, instead of borrowed from other industries. Using low-cost, mobile, and easily operated equipment does not only allow each design-and-build process to be customized toward its specific architectural goal, it also allows architects to operate independently and directly within situations or contexts that were previously unaddressed. Similar to how scripting has allowed architects to customize standard CAD packages for their individual design processes, custom fabrication devices enable the exploration of many new ways of integrating the digital and physical realms.

An example of this type of exploration in other industries is the RepRap project by Dr. Adrian Bowyer, which is based on an open-source, low-cost 3D printer for the production of small consumer products. The 3D printer is developed through a community of users and designers that form a larger network of ongoing improvement and exchange, and is intended as a tool to democratize the way in which consumers can design, manufacture, or buy objects outside existing industry constraints.

The work presented here investigates similar low-cost technologies and how they might operate at an architectural scale. It explores how design-and-build processes can be set up around these technologies, considering buildings to be part of a larger ecology that incorporates communities of users, technologies and materials, and other performance criteria that shape space.

2 SCRIPTING ARCHITECTURAL DESIGN

The linking of digital design and fabrication naturally leads to the consideration of basic principles or rule sets that guide the range of different outcomes of a conceptual design process within the limitations of a chosen material system. As Dr. Mark Burry and many others have pointed out, this type of "parametric thinking" is not a particular recent phenomenon and can be recognized in Gothic cathedrals or in the work of Antoni Gaudí. Michael Weinstock writes that "the abstraction of principles from the way in which biological processes develop a material system can be highly instrumental in the conception of architectural processes" (Weinstock 2010). Weinstock points out that natural material systems are often rule based and use principles of organization that integrate structure, material, and form. Applying biomimicry principles to digital methodologies allows them to become generative, if a feedback loop between evaluation and design is incorporated into the digital process itself. In An Evolutionary Architecture, John Frazer demonstrates the effectiveness of generative design processes in which the aims and evaluation criteria are clearly defined, and understood as interactions between the several agents (Frazer 1995). The process that directs growth and adaptation of structures needs to be defined in relation to an environment, incorporating parameters of limited resources, competition, and external pressures.

The projects presented here are based within this paradigm, aiming to set up generative digital design processes that incorporate specific material system properties and a mechanism to adapt final outcomes toward their context. Yet instead of setting up a virtual environment inside the digital domain, we apply generative models to the real context, using sensor technologies to measure and evaluate physical structures as they grow.

figure 1

figure 2

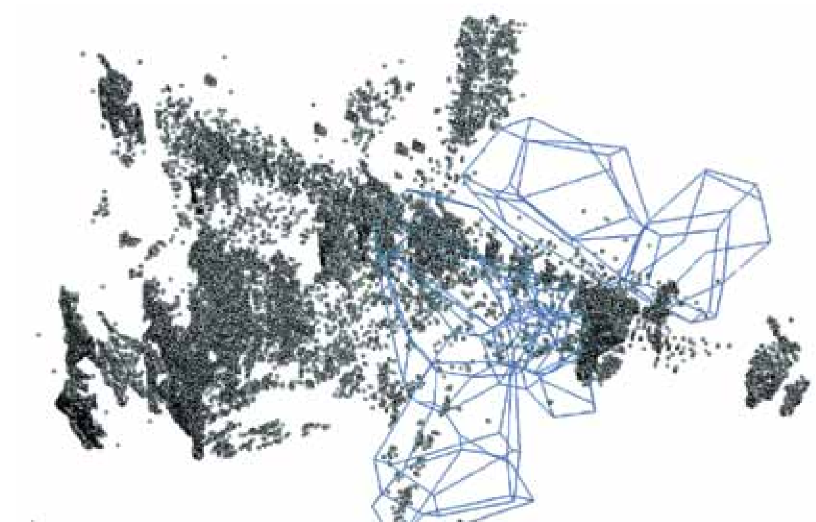


figure 3

figures 1, 2 and 3

G-Cloud project from 3D scans of people's movements through the site, materialized with help of a CNC pointing device as a triangulated timber structure.

3 SCRIPTING MATERIAL FORMATION

The integration between scripting, materials, and fabrication technologies is significantly explored in the work of Gramazio and Kohler, with some of their most iconic projects built out of digitally programmed bricks. Their design explorations are based on the sequential layering of material, which is directly analogous to the sequential looping of their digital design process. They write that "when architecture becomes the design of material processes, we no longer have a static plan in front of us, but a dynamic set of rules. We design a behavior" (Gramazio and Kohler 2008), suggesting that the choreography of the production process based on machine anatomy and movements is an important driver of design.

The inclusion of concepts of behavior might imply that more control could be handed over to design-and-build machines, and instead of programming fabrication sequences they might be equipped with sensing and decision-making abilities, allowing them to become intelligent partners in the process. Our research is related to this ambition, but with the acknowledgment that there must be a conscious creation of a programmed system of rules and fabrication machine behaviors, to allow for a certain amount of flexibility in implementation while at the same time safeguarding intentional qualities of performance by the structures resulting from the process. The architect's new design

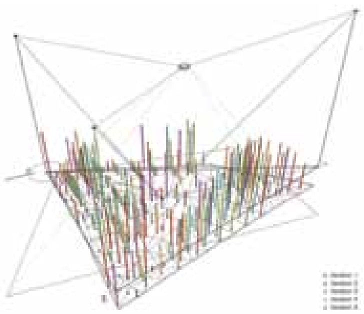


figure 4

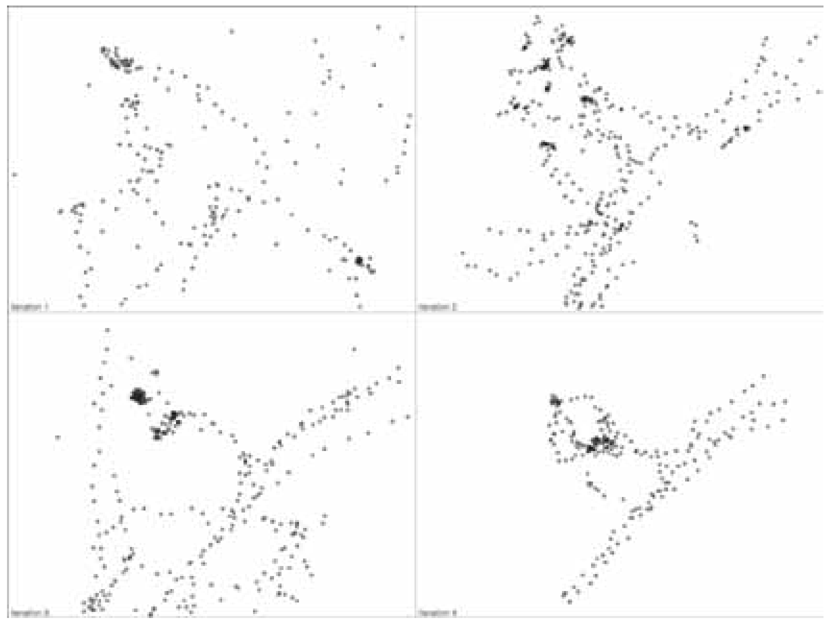


figure 5

responsibilities and opportunities will be concentrated in the "programming of the system," developing and testing genetic codes and implementation scenarios which allow for an open-endedness to incorporate unpredictable requirements raised by users, context, and site.

4 TESTING INTEGRATED DESIGN AND FABRICATION SYSTEMS

Our projects are conducted in the context of academic workshops open to students and practitioners, in particular during the MakeLAB Visiting School, which is held annually at the Dorset forest campus of the Architectural Association. Several processes and techniques had been developed separately earlier, yet toward the common goal of testing a complete working model of an automated digital design and construction process, investigating the topics described above.

The first project, titled G-Cloud, evolved around a scenario that included an aggregate material system with simple connections, and a digital workflow that translated 3D scanned data of people's movements and densities toward a corresponding cellular structure that traced and articulated the boundaries of the movements. A semi-automated design workflow was set up to handle the translation of the point cloud information from the 3D scans to the specific geometry to be built, using cell-packing and tessellation algorithms (Figure 1). The design method was calibrated to translate higher intensities of movement into increased densities within the structure, visualizing previously invisible qualities on-site and guiding subsequent visitor movements along specific paths.

To construct the design on-site, a custom-built point indication device was used, which allows one to computer numerically control the length of three wires on spindles attached to stepper motors (Figure 2). The wires were installed in a site by attaching pulleys to three existing trees, transforming any site into a CNC working envelope. Corresponding control software was used to move the pointer to specific coordinates in 3D space, enabling humans to measure, cut, and install new members onto the existing structure. In this scenario, the device is only used for its most important task: the transfer of precise construction information from a digital model onto a 1:1 building site. The human

figures 4 and 5

Project Stix. Density maps and timber stick patterns generated by webcam monitoring of people, showing the iterative refinement and densification around pathways and hangout spaces based on an active negotiation between users and site.

figure 6

figure 7

collaborators do tasks that they can do better than machines, such as the manual handling and connecting of building elements on-site (Figure 3).

G-Cloud demonstrated the potential of a generative design process and the relatively easy implementation of a CNC pointer device, which eliminated the need for the prefabrication of large numbers of mass-customized pieces. The shortcomings of the project included the lack of feedback between the performance of the physical structure and the digital design model, which therefore was unable to respond to changes within the site. Two successive projects have been set up to overcome this, by automating the design workflow and linking it to continuous monitoring of the site.

5 IN SITU GENERATIVE DESIGN AND FABRICATION

The project titled Stix explored a fully generative, rule-based design strategy that was based on the monitoring of people's movements through a particular forest site, recorded with a webcam suspended from the trees. Its material system consisted of timber sticks placed vertically within the terrain, chosen for its ease of construction and the compatibility with the CNC device. The vertical orientation of the sticks would allow the wire pointer to be used in between the elements, enabling the system to place additional pieces within areas that would have already been built up.

The project was designed and built in five iterations, using the webcam to record people's movement patterns, which were automatically translated into geometrical patterns for the timber stick formations (Figures 4 and 5). The movements were recorded during breaks in between the building activities when people were asked to pass through, explore, or inhabit the site. Each iteration would result in a construction pattern that would densify the site in areas that the people had not occupied, using simple rules to determine elements' heights in relation to their distance to populated areas. A gradual refinement and articulation of circulation and inhabitation areas occurred within the digital design model and physical space, thus allowing the final design to emerge out of an active negotiation between material and users around the real experience of the installation in the site (Figures 6 and 7).

6 CONTINUOUS ON-SITE SCANNING, DESIGN GENERATION, AND CONSTRUCTION

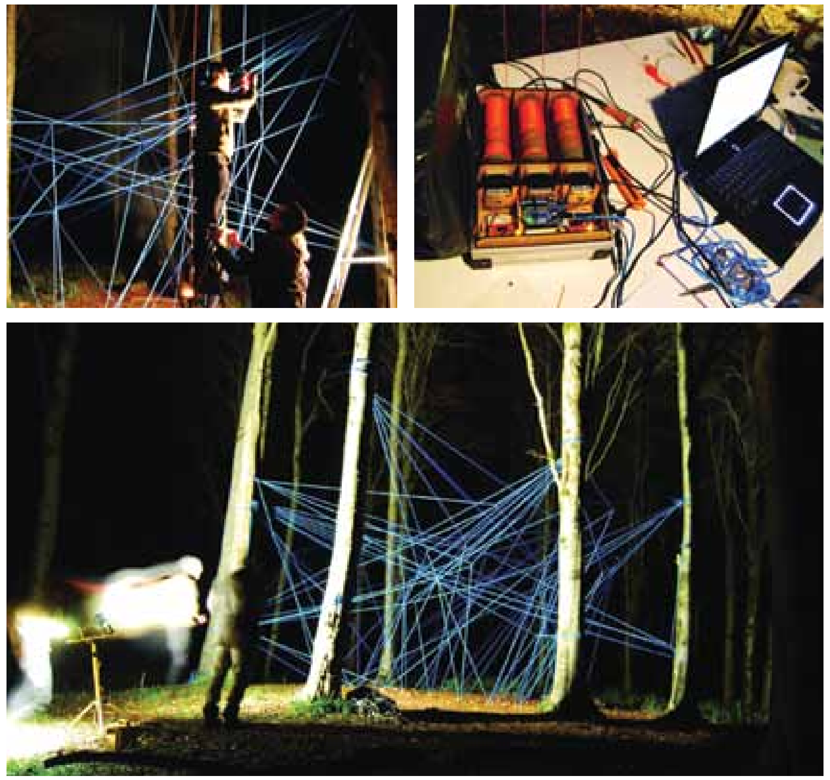
The project titled Blue used a similar wire pointer device as described before, but in this case it was connected to a dynamic digital design model, continuously monitoring the site. This system was set up using a Microsoft Xbox Kinect 3D camera, which was initially used to scan a person moving through and inhabiting the site, to determine a central area around which an enclosure would be built out of blue rope.

figures 6 and 7

Construction and final installation of the field of elements on-site, using a webcam suspended from the trees (blue wires) and a CNC point indication device (orange wires).

figures 8, 9, and 10

Wire structure produced through an ongoing process of scanning, generative design, and construction within the site.



clockwise: figures 8, 9 and 10

The corresponding construction methodology was based on simple rules and performance criteria, instructing people to install a growing wire network that was fully in tension. A digital procedure connected to the 3D camera was continuously measuring color and light values in the site, each time determining the lightest point around the perimeter of the central area at a certain height. It would then calculate the corresponding points at the ground and three neighboring trees, and use the CNC wire indicator to guide the people attaching blue wires into the site. Additional rules to avoid self-intersection caused the emerging sequence of points to slowly encircle the predetermined void and increase in height, gradually forming a three-dimensional enclosure (Figures 8, 9, and 10). The system's ability to sense and locate the blue color of the ropes already installed resulted in a network that was both regular and differentiated, showing various levels of porosity based on its orientation toward the light. The experiment showed how simple rule-based logics can result in a complex and highly adapted, inhabitable structure that demonstrates emergent qualities within the site, its precise material formation unpredictable and undesigned yet its final performant qualities as described within the rules of its procedural design.

7 CONCLUSIONS

The research presented in this paper explores the opportunities found within the integration of sensors, material systems, and fabrication devices into generative on-site design and construction strategies.

It has shown how monitoring a set of properties can drive consequential design adjustments that can be implemented right away, adapting the final outcomes toward the intended functionalities. By creating feedback loops between environmental sensory inputs and construction implementation, it is possible to explore strategies for fabrication where the final construction is not predetermined, but instead produces emergent qualities based on performance-based rules.

The key potentials of this approach may be:

Architectural structures can be produced on-site, with specifically adapted geometrical and material organizations. Buildings can be better equipped to perform within their context, with integrated functionalities and environment-specific, performance-based features.

Architects may engage new types of projects and achieve solutions for areas and programs that are currently not yet addressed. The increased control over production offers a democratization of design decision-making and facilitates negotiation between different parties in the design process.

The role of the architect using these methodologies may shift from controlling the end result to designing a process-based, quality-driven generative method, allowing successful methodologies to be implemented toward a range of programs and sites.

The research may increasingly incorporate intelligent behaviors, mimicking processes of self-organization as observed within nature. Providing an alternative vision to static and idealized architectural solutions, these methodologies are based on the unpredictable and dynamic processes that inform real-world architectural challenges and briefs.

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