Layered subsumption in intelligent material building systems

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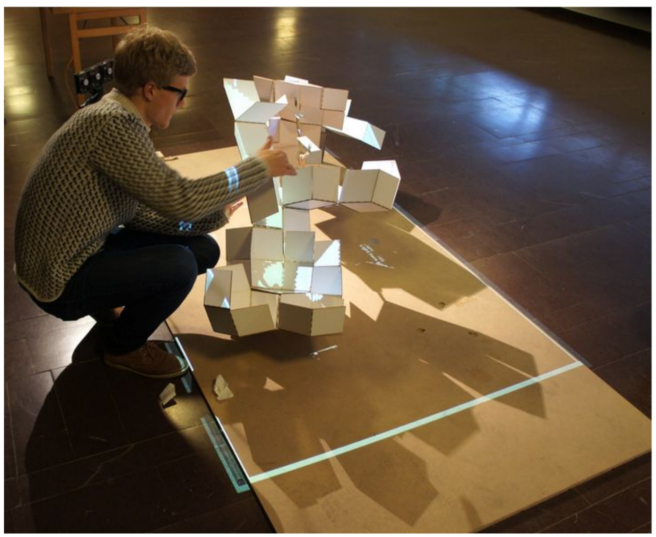

Figure 1: User adding a unit to the cluster

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Abstract
The paper investigates how robust layered subsumption is acting both digitally and through functionality embodied in the material of a building system of architecture. We describe a building system with embedded computational control over the building process, with the purpose of arguing how layered subsumption exists seamlessly shared between the digital, and the physical material of the system.

Roboticist Rodney A. Brooks argues, subsumption being a robust digital control system for artificial intelligence when being in interaction with the real world [3]. If a system using layered subsumption is able to modify its entire environment, we argue, that subsumption must be found embedded within the morphology and material of the environment.

Author Keywords
Subsumption, architecture, embedded, tangible, embodied, design, architecture, systems, interface, interaction, robot, artificial intelligence, AI.

ACM Classification Keywords
H.5.m [Information interfaces and presentation (e.g., HCI)]: Miscellaneous.

Figure 2: User attaching units to the cluster according to the projected feedback

Introduction

An adaptive, self-adjusting building system from architectural research is discussed throughout the paper. This building system grows two clusters from the ground up, using cardboard elements as building blocks. Under the initial start element, three pressure sensors are used to sense and balance the weight distribution of the clusters. Light and airflow sensors are in addition to the pressure sensors used for guiding the growth of the clusters. As the presence of the structure interferes with the sensors, the system in turn attempts to guide the growth of the cluster, so there is a feedback steering the growth process. This guidance is done through projecting colors onto the cluster.

Notions from artificial intelligence and architectural thinking are used for understanding the detailed interaction between the environment, the digital model, the user and most important the morphology and material of the physical building system. This paper claims, that if the system controls the environment itself, the subsumption must be found embedded even within the morphology and material of the environment.

Related Work

Architecture has over the past decade been heavily influenced by both new industrial materials and development in information technology. The confluence of these two areas has enabled architects to investigate complex material compositions within architectural designs. "Material systems" often actualized through intricate flows of information from the computational models towards the physical material [4]. The paper will deal with the consequences of information flowing from material compositions (materialized architecture) towards the virtual computational models. The research described deals with experimentation reviving the praxis of physical form finding analogous of the research of Frei Otto [6]. In form finding, equilibrium is reached through the interaction between natural forces. This research creates similar form finding processes but enhances these by having sensors and computation in the loop. These experiments have required users to interact and support the systems as acting agents, effectively rendering these processes into large tangible interfaces.

Tangible Interfaces are characterized by a close coupling between the interface and the digital model. Tangible interfaces can be expressive or exploratory, depending on the the relationship between the digital model and internal mental model the user develops during interaction [5]. In an expressive tangible system, the tangibles embody and represent user actions, if we see tangible as form, and action as function. Then the expressive system has a correlation between form and function whereas the exploratory does not need to relate form to function. In an exploratory tangible system, the tangibles do not embody user actions. The user does not focus on own actions, on the history of the interaction with the system, but focuses on understanding how the system works, on exploring the digital model [5]. Form does not have to fit function because the users goal is to understand form and context.

The distinction between these two types of tangible systems can be compared to the two types of design processes described by Christopher Alexander: unselfconscious, where form fits function and the selfcounscious, where form can be invented without close coupling to function [1]. Adaptation, self-organization are principles governing the unselfconscious processes, while In the selfcounscious prcesses form is derived based on predefined design principles. "In the unselfconscious

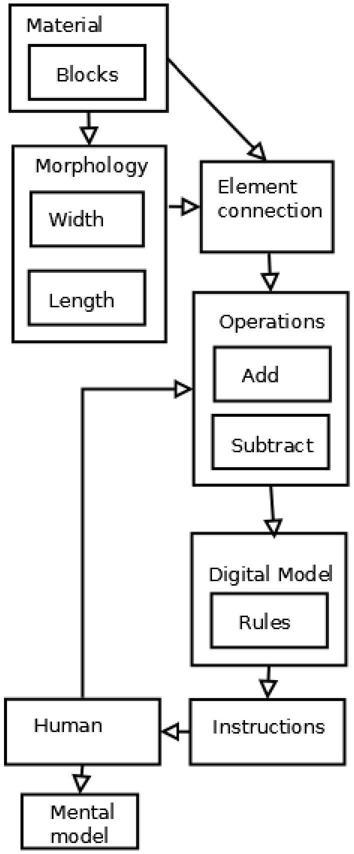

Figure 3: At a higher abstraction level, the main elements of the system are the building blocks, the possible operations given by the physical limitations of the material and environment, and the feedback enabled by the digital model

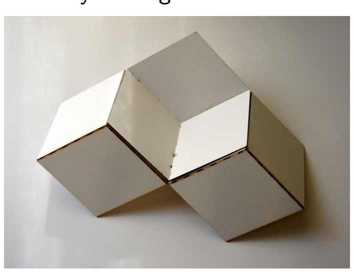

Figure 4: Three building units

culture [here meaning process] a clear pattern has emerged. Being self-adjusting, its action allows the production of wellfitting forms to persist in active equilibrium with the system. [..] it is a property of the emergent self-conscious system that its forms fit badly" [1].

The adaptive, self-adjusting, tangible system can be understood as what Rodney Brooks describes as layered control system, he proposes a framework for controlling mobile robots based on layers of simple, autonomous control modules or finite state machines, that can subsume lower levels by suppressing their outputs. Each module has access to entire available environment information and communicates asynchronously with other modules [2].

The paper describes this adaptive, tangible, self-organizing system, and discusses how layered subsumption can be regarded as a pervasive processes through the entire system, and how certain higher layers exist only in the physical material as morphology or material properties in a tangible interaction with the user.

Building System

Building blocks
The unit building block consists of three rhombic plates that are connected over three shared edges to constitute a rigid entity. These building blocks can be connected to the cluster by gluing any of the three sides to any other unit in the cluster. This way the cluster can grow in many directions and create various larger geometries like strings, plates or solids.

Sensors
Three pressure sensors placed under the initial elements sense the balance of each cluster, while two light sensor areas sense the shade and reflection and air flow sensors sense airflow. The sensor values are gathered by a central processing unit. This unit has a main representation of the system which is aware of positions of all sensors. A 3D camera is constantly scanning the structure and reporting to the CPU where the cluster is detected.

Ruleset of the system
The rules are prioritized in hierarchy where balance of the cluster is of highest importance (Fig. 6). The three pressure sensors under the initial element simply finds the one with least weight on, and assigns the next element of growth to that side of the structure, this way leveling out the difference in weight. Second is the light distribution. Two sensors placed in the ground level compares values and the cluster is guided to build shade over that particular area. Third is evenly distributed airflow. Two air flow sensors compare values and an obstruction is being build in front of the one with the most airflow.

In order to prevent the growing cluster from falling over, balance has the highest priority. But as long as the structure can build with regard to higher level criteria, and while the cluster is in balance, these criteria -or higher levels- will subsume the lower level of balance (Fig. 6).

Initial conditions
Initial conditions are important in this system as they are in all unselfconscious processes: "we must assume that there was once a very simple situation in which forms fitted well. Once this had occurred, the tradition and directedness of the unselfconscious system would have maintained the fit over all later changes" [1]. With the cardboard blocks, the initial condition is given by the base of the cluster that coincides with the placement of the pressure sensors, and influences the distribution and computation of the balance of the physical cluster. Its

development depends on the projected colors and on the decisions of the user.

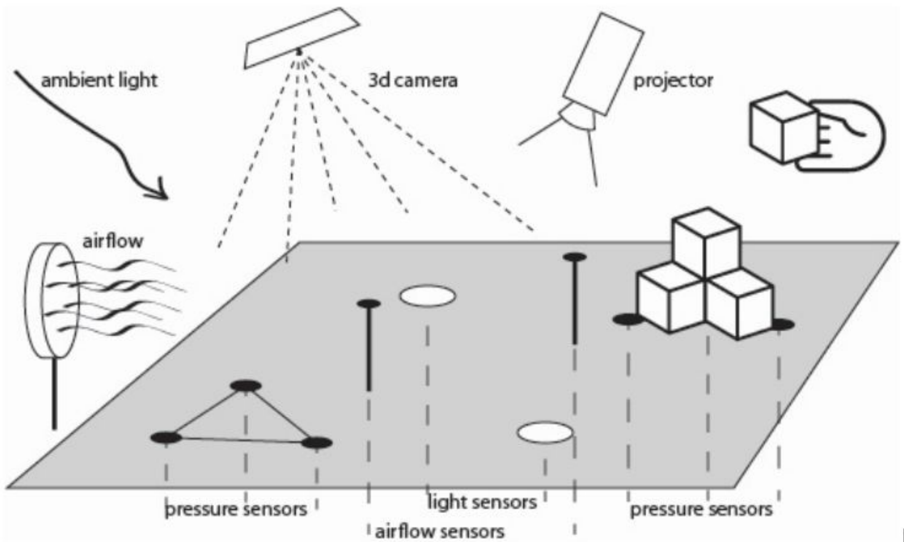

Figure 5: Overview of the elements and environment of the building system

Growth, user, material and rules
It is now up to the user, within the given constraints, to determine where to connect the new unit exactly, because many aspects can be assessed in this process. The cluster will, depending on the progression, offer a multitude of angles and surfaces, both inside and outside to adhere another element onto.

Discussion

Subsumption levels embedded in morphology and material
As the cluster is constituted by rigid plate units, it facilitate various three dimensional figurations. These very different opportunities for attachment is the reason why this morphology itself can be understood as embedded with subsumption levels. The limitations of opportunity can also be understood as a resistance in the process, C. Alexander describes as the resistance of tradition, or viscosity of a process [1].

The cluster will - depending on its current formation - offer opportunities for improving different aspects. As all additions apply weight, they all perform on the level of balance. When lower levels are suppressed, the units start to act differently as shade, reflectors, obstructions, structural repairs or aesthetically. Structure of the layers as shown in fig. 6 means that for any of the higher levels to act, balance must be maintained at all times.

When testing the system, it seems that the control system works well when the user is interacting with the system. Often users are initially focused on the aspects of balance, they take an explorative approach to understand the effects of certain placements, waving, pushing shading the cluster.

Subsumption levels embedded in the environment
Similarly as Brooks argues that the complexity of behavior is inherent in a complex environment, we believe that a building system like this only achieves its complexity and relevance through the interaction with a real environment i.e. in the form of airflow, light flux, and user interaction.

Adaptation emerges as the user interacts with the environment, affecting light and airflow, while both the system and the user makes decisions, the cluster self-adapts and create counter influences on the environment, the sensors and in turn the system and the user. As the system facilitates multiple, possibly conflicting aspects, in example if the shade of light brings the cluster out of balance or unintended obstructs an airflow. It seems subsumption framework governing the iterative growth and handles the task. Self adjustment is achieved through rules that enforce the principle of balance for enabling cluster growth simultaneously in various directions.

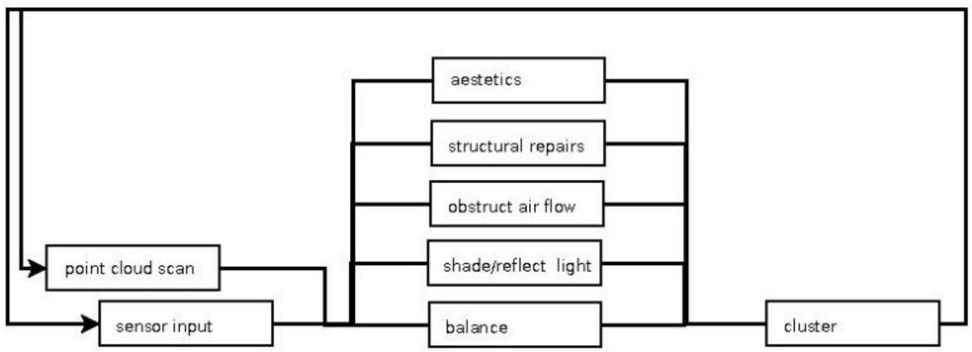

Figure 6: "Control is layered with higher level layers subsumng the roles of lower level layers when they wish to take control. The system can be partoned at any level, and the layers below form a complete operational control system" [3]

Conclusion

The physical morphology and material properties of the elements play a central role as they modify and are part of the environment. The resulting form of the cluster is a consequence of the morphology of the building blocks, the additive process of and self-adaptation. The cardboard morphology offers through its particular angles and measurements vast but limited opportunities for placement of new elements. It is these emerging constraints and opportunities in the material and morphology which can be understood as "layers".

The layers of subsumption are crucial as control system and they clearly transgress the digital system into the physical materiality of the environment and even into the user senses and rationale, this overlap happens through the exploratory tangible system. It is difficult to determine where the intelligence or creativity lies exactly, but the system facilitates and guides a somewhat intellectually difficult task shared between the digital, the material and user interaction.

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