ABSTRACT
Since the introduction of non-standard design to the field of architecture, we have seen a diminishing interest in the work of serialized units as a design strategy. On the contrary, every building block has become different as enabled by digital fabrication technologies and CNC manufacturing.

In the advent of the current energy crisis and technologies of distribution that allow crowd-sourcing as a design strategy, the “Polyomino” project attempts to re-consider serial repetition through a framework of combinatorics and graph theory, one in which we consider geometry as a data structure for a plethora of design variations.

“The designer becomes a designer of generating systems – each able of generating many objects – rather than the designer of individual objects” (Alexander 1968).
ARCHITECTURE NON-STANDARD

Non-standard architecture has certainly become a contemporary design paradigm; one in which we could theoretically avoid serial repetition of parts and allow for mass customization, where every component could be tailored to the specific needs and performance of a building. This idea suggests an ideal scenario where digital files could directly talk to digital manufacturing machines (file-to-factory) and, through the use of scripting, a designer would be able to constantly generate the differentiation of form without the laborious task of physically modeling every single component. The “non-standard” denomination can be traced to the Non-Standard Exhibition in Frac Centre, Orléans, which focused on ideas of mass customization in computing and design strategies. One of the central figures in the exhibition, Kas Oosterhuis, describes:

I have my roots in the paradigm of repetitive serial prefabrication of the 1960’s... While a group of Non-standard architects label their architecture with names such as Liquid Architecture, Hypersurface Architecture, Hybrid Architecture, Animated Architecture, Transarchitecture, Performative Architecture, Machining Architecture, Evolutionary Architecture and Generative Architecture, we realize in our design practice a very pure form of the File to Factory design and Build process which we have based on the principles of Swarm Architecture (Kas Oosterhuis, 2006).

Oosterhuis attempts to demarcate the non-standard paradigm as a pure relation of form and fabrication process, while allowing his own “swarm architecture” term, one of real-time communication between building components in an interactive fashion, to be one step beyond as it considers socio-special apparatus.

“Non-standard” derives from non-standard analysis, which describes the use of infinitesimal numbers for calculus. In this sense, architecture borrows a mathematical term to describe the architecture of the continuous rather than the discrete; an architecture of infinite variation and infinite potential v software has made non-standard design a possibility in a digital format, using NURB geometries or recursive smoothing algorithms, digital fabrication strategies have struggled to catch up with the resolution available in the computer, and are often compromised in low-res penalization strategies to conform to the infinite smoothness of a spline.

3D printing is one of the few technologies that promise to enable a closer materialization of complex shapes without the compromise of faceted tessellations as a necessary post rationalization of geometry. Together with 3D printing, designers have started conceiving the possibility of the dissolution of tectonics, an idea that would remove the necessity of parts, where material transitions would be defined by intensities and interpolations of material qualities, performance and appearance. One cannot help but stop to wonder that if we were to have such technology at an accessible price, would we really want to print a building as one monolithic differentiated fabric? Is this a paradigm coming from the architectural field itself or the linear projection from technology advancements steering corporate utopias?

HOLISTIC ASSEMBLIES

If we are to re-consider alternative paths, we need to first identify what is wrong with what we have and how are we implementing it. In the world of serialized repetition, the car sits perhaps at the center of the paradigm; words like ‘Fordism’ not only describe an industrialized and standardized way of mass production, but also a socio-economic context of mass consumption.

It is certain that in this way we can steer architecture away from such practices, as architecture has arguably been a discipline of ad-hoc design; one in which site and program change from project to project and no means of standardization or mass consumption are actually practical.

But not all serialized products seek standardization. With the advent of the computer, we have started to conceive products that do not offer a final solution, but rather the means to expand and allow others to create. The product becomes not the final experience but the means to expand on content, developed by the user. As users become producers, the role of mass consumption is questioned.

The classic Fordist assembly is what I describe as a ‘Holistic assembly’, one in which all the parts work with each other to describe a whole. It is perhaps the model of the jigsaw puzzle, where every unit has a place and by knowing how to put the pieces together we can arrive to the final output. This is the current model of architectural design today, where digital manufacturing, post rationalized, non-standard design, creates thousands of parts to be assembled in one unique way. The blueprint is singular and describes the end goal.

Digital fabrication in its different shapes and forms, including 3D printing technologies with the promises of dissolution of tectonics, suggest the same relation to a user driving a car, a user as a spectator and a consumer of a final product, it is not open to be anything else.
COMBINATORICS, NOT PARAMETRICS

The term combinatorics coming from mathematics describes the studies of the structures allowed by a finite set of discrete units. In its definition, the term demarcates a difference from non-standard calculus identifying that it operates in the realm of the discrete rather than the continuous. It also denotes the use of “finite”, countable units, as opposed to the variable units described by a parametric model.

In this context, I understand parametrics as a design paradigm that has allowed for the computational fitting of parts to a non-standard form or design. Its core function, is to vary the “parameter” or number of components necessary to allow a material system to describe a geometrical form. It is precisely the work of post-rationalization of infinitesimal surfaces into all sorts of material tessellations.

In a combinatorial system, on the other hand, individual units are a given and the computation deals with the possible combinations of such units. In this context, the outcome is what needs to be studied, as it is open and indefinite.

The difference between parametrics and combinatorics goes beyond what we understand as the type of differentiation. The parametric model can only operate in the definition of intensities or degrees, as the intrinsic topology of the data structure is fixed. A combinatorial model precisely misses the topological diagram, and this is what I call “the missing topology mechanic.”

The topology is the diagram that links pieces together defining the information that would differentiate a structure from pure randomness. The problem of combinatorics has to do with negative entropy, as opposed to post-rationalization. While the parametric model can vary in intensity, the combinatorial model can vary in kind, describing fundamentally different assemblies from either a partial or a full extent of the “building set.”

NON-HOLISTIC SETS

Some of the most paradigmatic examples of combinatorial systems have been toys like LEGO or DUPLO, which describe a finite tile set that could be explored by a user. In this example, the child plays in order to discover the topology of the units. In many cases, such systems or toys come with an instruction set that would guide the user from chaos to order. Soon, such instructions are discarded to explore the tile set in an open-ended fashion.

While a particular LEGO product will contain the specific pieces to be assembled into one final structure (the jigsaw model), LEGO as a system is a non-holistic set. By this I mean that it does not describe a whole, but rather just a discrete relation of parts. Only some of those parts arranged in one particular assembly could become a particular outcome, but they also might not.

A non-holistic set lives beyond the space of instances or outcomes defined by a user. This is a differentiation that Christopher Alexander makes between “Systems”, and “Generating Systems” or “Generative Systems.” For Alexander, “Systems” need to have a recognizable holistic behavior. He explains:

In order to speak of something as a System, we must be able to state clearly: (1) The Holistic behavior we are focusing on. (2) The parts within the thing, and the interaction among these parts, which cause the holistic behavior we have defined; (3) The way in which this interaction among these parts, cause the holistic behavior defined. (Christopher Alexander, 1968)

On the other hand, a “Generative System” as described by Alexander, is the building block of a Holistic System. He describes:

We may generalize the notion of a generative system. Such a system will usually consist of a kit of parts (or elements) together with rules of combining them to form ‘allowable’ things. The formal systems of mathematics are systems in this sense. The parts are numbers, variables, and signs like + or -. The rules specify ways of combining these parts to form expressions, ways of forming expressions from other expressions, and ways of forming true sentences, hence theorems of mathematics. Any combination of parts which is not formed according to the rules is either meaningless or false.” (Christopher Alexander, 1968)

I would argue that the design of such sets need to be conceived as an open-ended speculative material, one that can engage with user-driven differentiation and exploration, allowing crowd-source as a mechanism to extend the purpose of the outcome and take the serialized mass-produced units into the user-driven-content era.

POLYOMINO

As a starting point of the research project, it was decided to work with perfect packing polyhedra; a unit that could define a three-dimensional array without any gaps. From the different options available, the truncated octahedron was selected due to its number of neighbors in a voxel configuration and the ability to transfer vertical loads between units.
2. Polyomino Units in aggregation

3. 3 Printed Polyomino Prototypes
While our current design tools are well implemented to work with parametric models, we currently don’t have good tools to work with a combinatorial paradigm. The research unit desired to use Unity3D, a game engine with a strong geometric API, to allow user interaction with a geometric rule set.

The algorithm developed within Unity allows placing a new piece of geometry as a neighbor of an existing one. This is achieved by Raycasting from a player’s perspective view in the direction of the mouse, in a similar way in which a first person shooter game or Minecraft operate. The ray would detect the collision of an object and allow the player to create a new geometry perfectly aligned within the voxel configuration. In this way, a player can only generate geometries that work with each other, not worrying about problems of accuracy. This constraint might appear as a limitation for design possibilities, but if we think in terms of a game structure that is giving the player only meaningful choices, the constraint becomes the mechanics of a combinatorial approach. The second level of decision provided to the player is the unit’s orientation. Here, as previously described with the domino “dot” diagrams, units accept or reject neighbors depending on their orientation. This information is presented to the player for them to decide how to fix and continue developing a particular assembly. Here again the agency of the player is to rotate the units by jumping between the angles that keep the voxel arrangement persistent.

Finally, the ability to remove units from the assembly allows players to work back and forward trying new configurations that could be exported and saved for manufacturing or cataloging.

The truncated octahedron became the initial condition for topology studies; in a similar way in which a “domino” block uses dot patterns to describe possible connectivity between units, dots located in the faces of and edges of the truncated octahedron units would start breaking the symmetry of the voxel allowing for only specific orientations to have synergy with each other. The exploration of this diagrammatic rule set would become the basis for the design of an actual geometry, one that would understand the rules of topology and its potential combinations. The design of the geometry would focus on the use of tangent curvatures that allow to blur the definition of one tile, and define assemblies as molecules that could be re-purposed as a higher order of structure.
Most of Polymino analysis is based on cellular automata calculations derived from “Falling Sand Simulations.” Falling Sand, is a type of particle simulation sandbox game that allows pixels to operate as digital matter. Each color of a pixel would represent materials such as water, sand, vapor or even fire, allowing for the physical interaction to be simulated with often unexpected outcomes. A user can “paint” using different materials to set up and trigger a simulation. Water particles in contact with fire particles might become vapor, while vegetation particles grow in contact with soil and water particles. In a similar way, the interactions between different building types are described as discrete relations as opposed to a holistic system.

While Polymino currently only transfer geometric data among its units, the research is looking at how to add other criteria such as environmental performance or even user-driven actuation for active assemblies. The player freedoms or features available for the user need to be studied closely; while every new feature could open up a big door of possible designs, it would also make the design space broader and less intentional requiring the users to provide a larger amount of time and engagement to find meaningful combinations. This is a key property of games and combinatorial systems as described above. There needs to be a designed balance between what is possible for the system and the capabilities of the players.

The system needs to be designed in correlation with the geometric possibilities and its social target counterpart. Once the system is designed and refined by several iterations of play-testing, we can push and document the user generated content as a design outcome.

GEOMETRY AS A DATA STRUCTURE

Under the described set of constraints for connectivity of units and rules of propagation, the Polymino project can be classified as a combinatorial system, one that does not describe a holistic output, but rather an open-ended tile set. The project was further implemented to describe architectural assemblies that would operate as a structural envelope dealing with shading and structure.
The system, being based on a voxel, can grow from linear aggregations to surface-like two-dimensional arrays, and finally three-dimensional volumetric configurations that would require the redundancy of units to produce higher order and organization.

The Polyomino agenda has been greatly influenced by a new generation of combinatorial products such as Cublets, Little Bits, Atoms or Moss. These products fully embrace a combinatorial paradigm, taking the lessons from LEGO into the world of electronics and robotics. But most of these systems have a common ancestor: The Braun Lectron. The Braun Lectron system is a pedagogical toy developed in 1966. It is a building set for electronics. The systems encapsulate the principles of electric engineering to allow a non-expert user to experiment and create sophisticated operational assemblies. As described by the Lectron website:

Lectron is an electronic learning and experimentation system. It consists of standardized modules with magnetic contacts. Each Lectron block contains an electronic component or a connecting line. Through meaningful juxtaposition of blocks arise functional circuits with standard-compliant diagrams. ...with Lectron you can learn to understand electrical and electronic transactions. With each Lectron system comes a learning and instruction book. Its technical ease of use makes it particularly suitable for small-scale projects.

The time-consuming setup of conventional systems such as soldering, clamping, plugging and other craft skills, is eliminated in the Lectron system, so you can concentrate entirely on the creative work. Over decades, the Lectron system was continuously working and furthering its development; the components and experiments correlate to the current state of the art. The modular series covers almost all areas of modern electronics and is constantly being extended. ("Lectron - Elektronisches Lern- und Experimentiersystem - Das Lectron Prinzip," n.d.)

The Braun Lectron also presents another fundamental trait of a combinatorial system. While in a parametric system we would use algorithms or data structures to describe the arrangement of matter, in a combinatorial system the geometry is the data structure. The geometry has the ability to identify neighboring cells and generate communication between them. While a Parametric model has an extrinsic data structure, a combinatorial model has an implicit one. Simply by placing the units in a particular formation, the user is generating a physical type of coding. Also, as described in the original advertisement, the Lectron system makes it “easy” to play and create complex circuits. This is due to the encapsulation of complexity lowering the entry level for complex circuit design.
This notion of design and complexity encapsulation can only be approached with a piece of geometry with a development cycle much longer than the one we have to design a building. In the case of the Lectron, the unit has been patented and become a product that has been developed over decades. It is precisely this kind of encapsulated knowledge that is enabled by a combinatorial approach, opening the possibility of conceiving new product design as design of new architectural materials.

**DESIGN PATTERNS**

The implications of re-considering a serialized mass production of units that operate under combinatorics are not only formal, but socio-economical. On the one hand, the product, as described as a non-holistic design system, relies on new content generated by the user. The crowd source potential for designs insists that the final product is open-ended and engineered as a speculative building set.

Out of this crowd-sourced operations, we would inevitably obtain “design patterns.” Here I extrapolate the concept of software design patterns developed for Object Oriented Programming by “The Gang of Four” (Gamma, Helm, Johnson & Vlissides, 1995). The main idea behind design patterns is to obtain re-usable solutions to common occurring problems. This is implemented with the finite set of tools available in an Object Oriented Programming paradigm that focuses on the description and interaction of discrete units for development of algorithmic design. In the similar way in which design patterns are applied to software, formal design patterns could be approached as material assemblies.
In the Polyomino project the search for patterns would become a fundamental design strategy to generate larger configurations. The units are considered the fundamental letters of the Alphabet, but soon a community of users could describe a whole alphabet of words, sentences and paragraphs.\footnote{It is important in this point to draw a distinction between Alexander’s thinking and a current re-consideration of design patterns. While Alexander would suggest generative systems in order to address holistic systemic assemblies, this research proposes design patterns as examples and guidelines that could be altered, overwritten or even hacked. The research questions the fundamental necessity for holistic structures and develops non-holistic sets that could allow for crowd-sourced speculation.}

REVERSIBILITY

Perhaps the fundamental feature for a combinatorial system as presented in this paper is its reversibility. By this, I mean the ability of the system to be assembled and disassembled, allowing for trial and error, design search, but also the possibility of multiple outcomes from the same tile set. It is perhaps important to define in this context that this research does not consider architecture to be an interactive entity, but rather an adaptive contingent deployment of temporary structures out of units for many alternative configurations. The idea of self-assembly suggests certain autonomy of the system, while this description of contingent combinatorics suggests a co-dependence within a social system. This co-dependence is what I describe as gameplay.
Reversibility describes a different economic relation to matter allowing the unit to encapsulate more agency allowing for a larger body of knowledge and tectonic logic to be passed to a non-expert user. The ability for a system to learn is not defined by a learning algorithm that would control the behavior of the system but rather in the socio-matter relationship of design, crowd-sourced design and contingent deployment.

COMPATIBILITY AND EXPANSION: OPEN SOURCE

The described systems are still in an embryonic stage and will need to confront similar challenges of software design. They could be developed and commercialized as a proprietary product, sets that might be incompatible with other systems, but I would argue that their true potential relies on describing protocols for open source communication for combinatorial projects.

The fundamental idea is to allow geometry to encapsulate data and become the building blocks for a “geometric computation system”. Such an idea will rely not only on a vision or project but a community that could support, implement and expand the definition of the geometric set. Such social co-dependence has the potential to impact a much larger market than, the one architects operate in today, allowing users to free form and design without the need for architects. In this way we could start to think of poly-designer assemblies designed by crowd-sourced communities.

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REFERENCES


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IMAGE CREDITS

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Figure 4. Screenshot of Falling Sand Software.

Figure 6. Images from Atoms, Little Bits, Cublets and Moss.

Figure 7 & 8. Property of Braun Lectron.