Mereologies

Combinatorial Design and the Description of Urban Form.

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This paper discusses the ability to apply machine learning to the combinatorial design-assembly at the scale of a building to urban form. Connecting the historical lines of discrete automata in computer science and formal studies in architecture this research contributes to the field of additive material assemblies, aggregative architecture and their possible upscaling to urban design. The following case studies are a preparation to apply deep-learning on the computational descriptions of urban form. Departing from the game Go as a testbed for the development of deep-learning applications, an equivalent platform can be designed for architectural assembly. By this, the form of a building is defined via the overlap between separate building parts. Building on part-relations, this research uses mereology as a term for a set of recursive assembly strategies, integrated into the design aspects of the building parts. The models developed by research by design are formally described and tested under a digital simulation environment. The shown case study shows the process of how to transform geometrical elements to architectural parts based merely on their compositional aspects either in horizontal or three-dimensional arrangements.

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It is predictable that from powder to building blocks to building parts research into additive assembly will progress, allowing the placement of larger and more complex geometrical figures. Currently, one can observe a renewed interest in automata, their discrete agglomerations (Sanchez.2016) or the possibility of self-assembly. (Tibbits.2017) With this, the design of discrete arithmetic, and strategies of placement creating diverse ranges of spatial configurations will become more and more necessary. Analog to Durand’s explanation from building materials to architectural elements to compositional principles, investigations into discrete arithmetic are complementarily entering the scale of a spatial organization today. Similar to the traditional notion of the parti, the ultimate question underlying the shown research
is: does computation offer a new way describing a building; what is the form of computational spatiality? Parallel to the pioneering studies by Stanislaw Ulam, here the motif of a building part is embedded in the geometrical element itself.

THE DISCRETE SYSTEM
Since its pioneering days, computer science showed an interest in combinatorial problems. Early applications can be already found in the work of Stanislaw M. Ulam on the combinatorial problems in patterns of growth (Ulam.1960). In a sequence of research papers conducted between the Mid-1950s and 1960s, Ulam and his team introduced a computational topic to the discussion on composition: recursion. The studies were built on the research of cellular automata. Cellular Automata initially developed at the Institute for Advanced Study in Princeton by a team of researchers headed by John von Neumann allowed the computation of physical phenomena on a computer by their representation in a logical space. (Neumann et al.1966) The automata consisting of discrete units were able to perform fundamental decisions based on linked neighbor states. The model was scaleable allowing the calculation of chain reactions from the simulation of molecular reactions to weather forecasts and beyond. However, further investigations showed also that automata could be used not only for modeling but also for design. (Dyson.2013) In this scope, Ulam’s later research can be seen as the first attempts to transfer these logical machines back into physical space. The study explored the generations of patterns in two-dimensional space based on one geometrical figure and simple recursive relations as the arithmetic of an additive placement of the same figure. In the first generation, the initial figure is a square. Both patterns are produced from the same figure, yet they are different because they follow a different set of rules; although all figures are growing in the same way, the rules that manage how they connect are different. Comparing (Fig.01b) with (Fig.01c), it is clearly shown that there are different patterns. Although the same rules are followed when elements are altered, the outcome shows different patterns depending on the changes in the basic figure.

More than a generation later, these approaches have found their first translation into the realm of urban design. Julienne Hanson and Bill Hillier have applied the computational model of discrete growth to their study on the vernacular villages in the French Alpes (Hillier et al. 1984). In their research, Hanson and Hillier showed that the spatial character of these villages could be represented with a discrete system. Transferred from computation, the discrete system...
Arrangement of a discrete system of four-sided cells each with different ratio of connectivity, left: a ratio of 4, 4, 4, 4, 3 connected sides; right: a ratio of 4, 4, 3, 2, 2 connected sides. Comparable to (Hillier, Hanson.1984).

ARCHITECTURAL PRECEDENTS

Such combinatorial thinking can not only be found in computer science but architectural precedents as well. For example, during structuralism, the office building “Centraal Beheer” by Herman Hertzberger can be seen as a precedent for the computation of space (Figure 03). Through the concept of the free-space units that constitute the building blocks, the space in the building is divided into similar spatial cubic elements. A combinatorial relation combines these units rather than a fixed order; meaning, units are arranged in a way to provide a specific spatial configuration rather than following an order. The initial formal unit in the building is 9 * 9 meters blocks as repeated spatial units. Each unit is divided into four areas with 3 * 3 meters leaving a cross-shaped space in between as an additional space. The compositional design of this building represents the appearance of consistent applications. By giving users the rights to layout their blocks according to specific preferences and requirements that they need, there were no separations in one geometric unit at first, but later with the users’ interventions, it turned out to be various.

Here, positions of the internal separation walls are freely designed by the users but inside a limited
area of space. Encountering such thoughts is typical for architecture, by repeating these walls, the inner space is divided into smaller units. Vis versa, repeating the units is dividing the outside space into spatial zones as well. The ability to nest one element from the inside to the outside with the same relationship logic makes it possible to compute these arrangements. Sequences of the elements themselves are representing the roles of autonomous state characteristics, which now shows as the variety of space types, while the primary grid system, which served as the link between different units in the discrete system, was the basis of combinations of these units (Figure 04).

At the scale of the city, relationships between discrete elements cannot only be found in the relation between the grid and the plot, but also in considerations on neighborhood units, such as parks, and plazas. For example, the playground design in Amsterdam by Aldo van Eyck designed in 1947 (Liane Lefaivre et al., 1999; Figure 05) is an instance that focuses on distributive open spaces affecting the whole city. The playgrounds followed four major aspects. First, the landscape elements were designed in a very minimalist way to encourage the creativity of the users, therefore stimulating openness. Then, the modular application of the playgrounds: the basic elements such as the sandpits, stepping stones, the jungle gyms, etc., all could be rearranged in various configurations depending on specific requirements. The third aspect was the relation between these playgrounds and the surrounding urban tissue. Through the distinct distribution of the discrete playgrounds in the whole city range, the playgrounds seen as automata were not only linked to other playgrounds but also to several other “automata” of the city, like the street or the urban block. Fourth, these links were not spatially constrained to a grid or in specific dimensions, but mapped to more relevant aspects for a playground, like population density. In short, van Eyck designed an open, but modular discrete system including several scales with a varying number of linked neighbors. Each playground could be seen as one unit that contributes to the discrete system, just like the 9 * 9 blocks in the Centraal Beheer, with different possibilities of various internal design.

**PROGRESSING DISCRETE SYSTEMS**

Linking the history of discrete computation to recent investigations in machine learning and more specific reinforcement policies, it is worth considering the board game Go. Due to its simplicity, but nearly infinite possible variations the game Go became the ultimate testbed for research into Artificial Intelligence, most famous with the success of the neural network machine AlphaGo, widely celebrated even as “one of the mature AI applications which exceeded nature intelligence in a certain degree.” (LeCun.2015) Indeed, the AlphaGo board can be very comparable to the discrete system in the thinking of parts, and nesting relationship, the board in the game Go represents the space in which all the stones are being arranged. The board is limited within certain size and dimensions and divided into 19 * 19 grid. The size of the board with the rules that control the arrangements of the stones both together form the states that are needed for the discrete system. By analogy, different color stones and the basic patterns are the basic elements of the system while the rules are the relationships. Stands for a nearly perfect process of technological learning and evolving game strategies (Cade Metz, 2016), the neural network AlphaGo was built with the setup of a framework and a limited set of combinatorial rules. (Silver.2017) At the primary stage, it is trained from traditional data sets containing the moves of played games. The training could be accelerated by letting the network play against itself. The subsequent development of AlphaGoZero even did not depend on the primary input of existing data-sets. Through the iterative process, the application concluded the evaluation of its own outcomes. Without using historical data or human intervention, Zero’s network surpassed any previous achievements after just 40 days of self-training, even with some novel playing patterns that have not been predicted before. However, the Go framework consists of only a
Figure 3
Analysis of the Centraal Beheer complex by Herman Hertzberger. Different compositions inside one module.

Figure 4
The Discrete Automata System inside the Centraal Beheer Design Concept.

Figure 5
Analysis of a playground designed by Aldo van Eyck; alterations on one exemplary playground.
grid comprised of 19x19 lines, a set of 180 white and 181 black stones and only two basic rules. Compared with inputs, the self-training results are outstanding, but one may ask if such an approach based on an insufficient set of ingredients applies to the field of architecture and urban design. Compared to building complexity, one specific size board game could never reach the flexibilities.

However, the strategy how AlphaGo begins to recognize the board of the game might open the possibility for a future application of deep learning to architectural and urban scales. The network consists of a stack of layers starting with simple differentiation, like differing the color of stones. Step by step, the network proceeds in building groups and patterns. These situations could be referred to the layers thinking in building form, starting from the basic architectural parts to the scale of a city. By self-training, there is already a vast number of different basic playing patterns stored as data, from basic five stones to different scales. However, even with various scales, large scales could be downgraded into smaller scales. The AlphaGo network uses a nesting of patterns of stone arrangements. The nesting introduces a hierarchy in decision making and radically reduces the possible amount of permutations compared the flat consideration of the whole board. Such a concept of layering, also referred to as deep learning might be indeed comparable to the way complexity is organized in architectural considerations. So, in the following a case study shows how parallel to machine learning procedures, architectural complexity can be described with a discrete set of parts and rules.

**DESIGN RESEARCH - MERELOGIES**

The project starts with a geometrical element that can be defined as the general reading of a building part, combining in one part elements representing floors, walls, and stairs. Further on, those figures are arranged in two-dimensional and three-dimensional figurations so that the figures create specific spatial pattern comparable to layouts of a plan or a building structure. Based on local decisions the quality of space is formed by the geometry of the element. By this, comparable to the described discrete systems, the spatial quality is located in the possibility of chaining of the figures, ultimately in their geometrical properties. Therefore, local properties of the figure span the design space of the whole plan or building layout. The figurations resulting from chaining a distinct number of elements (see Figures 06 and 07) to local properties are stable and specific not in absolute measure, but in their characteristic qualities. Bringing up these relations into a higher level of complexity with combining similar figures, different patterns are produced from one version of the element by changing the local ratio of connectivity of the figure itself. In this instance, it can be said that the model space is designed to work with a minimal set of rules open for further addition of design intentions.

Besides, the resulted assembled form can be considered as a discrete system which is formed by discrete elements, which consists of a discrete system. Comparable to the described architectural precedents, the nesting of discrete parts allows articulating distinct features (Figure 08). Using the produced sequences recursively, meaning as a basic fig-

![Sequential chaining of a simple H-figure.](image)
Figure 7
Two-dimensional studies of recursive figurations based on the repetition of the same figure.

For a larger figuration, patterns can be refined more in scale and resolution (Figure 09). Observing the outcomes from the previous stage and evaluating what is desired, one could continue this recursive assembly process, with benefiting from the experience that has been built previously.

Framing the scale of the studies more architecturally, in a further step the discrete state decisions were projected to the basic differentiation between an inside and an outside. Similar to the shown Centraal Beheer concept, this allowed the nesting and grouping of discrete systems. Each subsequent interiority, externality is formulated as a discrete system on its own adding another layer of part-conditions to the building arrangements. With the definitions of a group in a group, the project tests the process of up-scaling through the way of building large scales upon small ones. Chained through layers of in- and externalities such arrangements can be described by states, as an interior inside exterior outside exterior.

CONCLUSION
The research shown exposes a strategy for the nesting of discrete patterns to a comparable scale of an urban form. That was done through the nesting of part-relations, a design process started from the basic geometrical parts and with different arrangements, from wall arrangement to sequences of rooms and building parts. Departing from the link between AlphaGo and the discrete system using the concept of the board in a board in AlphaGo game as a layering strategy for nesting more complex patterns created by geometrical element, it is possible to speculate on an upscaling the project to the scale of the city. Comparing with the board of Go as a testbed, architectural arrangements can be described as chaining and nesting of multiple discrete systems. Depending on the simple part relationships and building upon them more complexities through nesting and layering, it can be projected that an adaption of machine learning and more specific deep learning strategies to architectural and urban form might be not so far.
Figure 8
Figure 9
Computed arrangement with 200 parts at an urban scale.
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