The city as an element of architecture

Discrete automata as an outlook beyond bureaucratic means

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This paper contributes to investigations in the field of aggregative architecture, discrete material assemblies, combinatorial ontologies and their possible up-scaling and implications on urban design. It argues that the digital definition of being discrete is not compatible with earlier, semantic definitions and their connotations on larger scales. Comparable to the breakthroughs in additive assembly by the use of discrete computation this paper demonstrates that the upscaling of discrete notions leads to considerations on the nesting and grouping of parts, here referred to as mereology. Via the means of an exemplary study it introduces the vocabulary of mereology and shows how complex compositions can be articulated with a collection of part-to-whole relations.

Keywords: mereology, discrete automata, aggregative architecture, part-to-whole relations, urban design

THE CITY AND ITS ARCHITECTURE

The notion of to be urban, or in other words of being situated in a city becomes rather interesting with the digital forms of cities designed by pure quantities: data. Strangely, today's abundant information inverses the foresight of an immaterialist city. The completed anthropomorphic scenography of our environment reverses as one looks to its main driving ingredient. Data becomes the missing link between the human and inhuman parts of the city as it makes things talk by pointing to its origin and author: the technical being. Here the role of architecture becomes crucial, as digital cities are always localized in their quantities, their parts, and their architecture.

In urban planning, one can observe an increasing tendency to describe, plan and share cities via logistic protocols and statistical means of big data. (Rossiter 2016) In the realm of digital logistics, buildings are here no longer singularly crafted enclosures, but reproducible products set within similar urban arrangements. (Easterling 2015) At the scale of the city, we face the vacillation of architectural entities purely as commodities. More and more cities are discussed with representations of occupation, ownership, and partitioning. Such representations are fundamentally different from the typical city-representations of the last century. In those former models, like the New York's zoning law, the city was established through the contour of its mode of production. The law manifested the city as a limit of buildable mass in relation to its plot. Thereby, city planning was seen as the regulation of that what has to be produced. Opposed to those former models, today cities are not discussed via methods of projective planning, but via logistic
protocols and bureaucratic means on speculative beings.

DATA ZOMBIES
First coined by Jonny Aspen as Zombie Urbanism, there is a dark side to such representations, especially in combination with big data. (Aspen 2004). In such models, a city is discussed mainly via general, mathematical factors, like interest rates. Here, the generalization of buildings to commodity plays a crucial point in their model making. These models are driven by economic abstractions turning cities into a giant, speculative warehouses of capital. Like any form of abstraction, such models have an enormous negative impact on live qualities in cities, merely through an increasing ratio between mortgage loan and average incomes. Comparable to other fields of big data applications, (Cathy O’Neil 2016) it seems as the adaptation of algorithms in urban planning and their exponential influence with the means of big-data increases inequality. Simply by one reason: The digital applications driving the data economy are based on choices made by (fallible) human beings. Many of these models encoded human bias into algorithms and therefore prejudice into software.

THE DISCRETE
Such an insight on algorithms can be traced back to the work of Gilbert Simondon, who already pointed out in his analysis of technical objects that “what is inherent in the machine, is human reality, human gesture, which is fixed and crystallized in functioning structures. The modern machines are not mere automata; there are technical beings.” (Simondon 1958) Such a notion of a technical being offers as well an opportunity, as it shows that every commodity is thought first as human institution before it becomes a part of an architectural object itself. At this point, we can connect to a renewed tendency towards discrete assemblies in architecture. Key is here a new notion of the discrete derived from the representation of an entity in object oriented programming. In reference to the programming paradigm - not to be confused with philosophical approaches (Leach 2016) - the term discrete leans on the concept of encapsulation, which in its consequence defines an object as an interface between an internal description and its external access. Internally, an entity is described as a pattern existing in a stable relation to its properties, abilities, and methods. On the other hand, externally an entity is defined by the kind of access to its resources and abilities through other objects. (Gamma 1995) Concluded from an external point of view, the possibility of a limited access means that descriptions of discrete objects might be incomplete. Externally seen parts of a system might be malfunctioning, yet from an internal point of view, it implies that discrete objects resist, behave, and interact. Res verse, considering the internal structure of an encapsulated object, discrete objects comprehend other forms, artifacts, and assets as its commodities.

What was originally established as an efficient handling of complexity to write software, offers an attractive opportunity as this paradigm manifests itself in the physical forms of our digital culture. Architecturally, the set-up of their interfacing builds digital objects. Interfaces are formulated not by their specific content, but via a protocol, which filters, groups and nests: no matter what. (Garcia 2014) The protocol differs from the form of the shadowed volume marked by the zoning law mentioned earlier and similar descriptions of the last century. The zoning law conceptualizes an entity semantically through the marking of a territory. Here, a shape or contour

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Figure 1
The twist-lock, part of an intermodal container, one of the first physical products of digital logistics; source: https://upload.wikimedia.org/wikipedia/commons/e/e5/Containerverriegelung.JPG.
carves out and separates shadow from air. However, to be able to separate, a general objective of cutting voids from mass has to be assumed in the first place. More computational speaking: a notionally standard scale is established to compare raw data derived originally from different scales. Using the concept of normalization, a carved territory is calculated and dependent on the set-up of the scale in the first place: it is a functional whole. (Rescher 1955) A territory, even if it separates areas from each other, is not discrete. Even the void becomes a part and is dependent on its initial conception.

In the recent past, computational performance amplified such functional dependencies simply by down-shrinking of parts to particles. Increased resolution led to more fine-grained determinisms, like in the case of a zoning law: the grain deflated from the building mass about the plot area, to the window panel allied with the sun-insolated floor area. Here a big-data approach adjusted the raw data of the façade-panels to the scale of the building envelope. Though, the new resolution has an uncanny side-effect: attributes of the window panel influence directly the program and thereby controls the interiority of the building itself. However, the calculus of the normalization is based on a measure relating to urban considerations between buildings and their contours only. The down-shrinking of semantic calculi creates a fallible transparency from building to building parts. Normalization simplifies complex relationships of the built environment to ratios, and in the most extreme case to an abstract ration like interest-rate alone. Here the digital version of the discrete offers an alluring alternative, as it is by default non-semantical and described as the pure act of partial sampling and nesting. Therefore, the discrete is inseparable from its compositional aspects, regarding its assembly or aggregative consistency.

**MEREOLOGIES**

Not defined by reference to content or form, the new discrete expresses the resonance of its parts.
Built on partial access, discrete objects are always in one or another way parts. In conclusion, architectural form turns into an aggregational stasis of intervals between part-to-wholes, part-to-parts, and whole-to-wholes. Strangely, part-to-whole relations were neither explicit articulated as a framework, but they were always part of architectural descriptions. Already Leon Battista Alberti rendered in his treatise architecture as a circular, compositional tension between the city-as-a-house and the house-as-a-city. (Alberti 1451) Comparable to the useful terminology of topology or morphology, considerations on parts can be discussed with the term mereology. Formulated in mathematics and formal logics, (Varzi 2015), mereology should be seen here as a collection of strategies dealing with part-to-whole relations in architecture. As a theory of part relations, mereology takes compositions as its ontological primitives. Opposed to set-theory, mereology does not start with null sets, axioms, or any predefined structures. Mereology presupposes the individual, the automaton. It begins with the description of overlaps between discrete entities, considered as parts. In this lies the disciplinary contribution as terminology in architecture, as it can describe architectural form purely as its composition.

Subsequently, in this view, the smallest bits of architecture are poietic objects: human-made compositions, and indeed, made for specific purposes. But here opposed to semantics, purpose, and more technically the functional dependency is an internal aspect of the design of the entity itself. As an illustration, one can review the perhaps first physical product of digital logistics: the intermodal container. The development of the standardized shipping container went hand in hand with the digitalization of trade and the algorithmic optimization of traffic routes, beginning in the late 1960ties onwards. To calculate the flow of goods, a smallest bit had to be established, which supports at any location the similar method of stacking and handling. For this reason, freight containers share a number of key features, globally specified in the standard ISO/TC 104. Worth noting is that the stackability is not determined by an expected rule set, but by the detailed description of two specific design aspects: the corner casting and twist lock. (Figure 1) Finally, the design of the twist-lock allows the global coordination, stacking, and alignment of shipping containers. Digital protocols mold here a distinct part, which did not exist in the first place. In short: Form manifests data.

Digital disposition differs radically from dispositional diagrams of the last century. Such forms of organization, most famously the Domino-House imposed a datum, beginning with a Cartesian space to disposition columns, slab and subsequent building parts to an architectural object. Contrary, digital logistics rely on discrete entities, like the twist-lock, where the form of assembly is an intentional part of the part considered as the whole in the first place. In digital logistics, one can assume that the whole is subordinated to the part. Concluding at large scale: the city becomes an element of its architecture.

First computational precedents can be found in the model of space-syntax and its investigations on the relation between local morphological relations and global patterns. (Hillier, Hanson.1984) Whereas, in contrast to space syntax, this research intentionally does not link spatial patterning to social information.
and content. Figure 2 shows a comparable study to Hillier and Hanson’s interest local linkages and their large scale figurations.

**The Resonance of Parts**

Both forms, digital logistics, and structuralism have in common that they design with the dependencies of group relationships. The one internally, the other externally. Both open the possibility to design with the access to parts, their comprehension, their incompleteness, in short: the resonance of parts.

Above all, in the field of material systems, a renewed interest in aggregational part-to-whole compositions can be observed. For example, research into Jamming-Based-Architectures (Zhao 2016) demonstrates that aggregated material systems can achieve stiffness and structural dimensions comparable to solid materials through the design of geometrical properties of a part even without structural considerations concerning the whole. In the field of architecture as precedents can be named the Self-Assembly-Lab at the MIT exploring information-rich materials containing assembly logic, (Tibbits 2012) and the combinatorial design studies by Jose Sanchez. (Sanchez 2016)

Complementary, to those ongoing investigations, this research deals with mereological model building. Specifically, this research explores possibilities of up-scaling and implications on urban design. Technically, a large proportion of the studies was carried out in simulation environments, using Processing and the game engine Unity. The modular architecture of these frameworks allowed the crossing of several software packages combining CAD-geometry, physics-simulation, graph analysis, classification, and clustering algorithms. Most of the following design studies were elaborated in a research-led teaching environment at the Bartlett School of Architecture, UCL London. The illustrations show an excerpt from the work of the Research Cluster 8, which is part of the post-professional architectural design program BPro-AD. The software framework developed by the author provided here a platform.
for the individual design studies. For a clearer understanding, studies from only one design project: “Wa/onderYards” by Chen Chen, Li Genmao, and Zixuan Wang are exemplary shown (see Figures 3, 4, 5, 6 and 7).

Figure 5
Accumulations of similar parts have congruent characteristics. Left: figure-figuration comparisons; right: linear-branching type leads to courtyard condition in large-scale arrangements.

SAMPLING PARTS
Framing the research to urban design, the smallest parts operate at the intersection between urban and architectural scale. One aspect of the research deals with the sampling of architectural parts from existing buildings. How can an architectural object be described as a composition of protocols, interfacing urban and architecture? Corresponding to the “composition over inheritance principle” in object-oriented programming, (Norvig 1998) architectural parts are here sampled in such a way that they express semantically polymorphic behavior. Borrowed from OOP, polymorphism allows the digital description of an architectural sample to assume different performances depending on its part-condition. Take for example the catalog of parts in Figure 3. The samples are mutually considered as courtyards and as compositions of i.e. stairs, windows, and floors. In the following, the polymorphic set-up supports the combination of several part-conditions in one arrangement.

Mereological sampling does not constrain a part to its relative proportions. As a bundle of partial, discrete statements, like the perpendicularity between a wall and a floor, mereological descriptions do not bind all dimensions equally. By default, such declarations are absolute and therefore asymmetrical. At first glance, absolute links seem to have a limiting effect due to their rigidity. But the resultant, partial directionality allows for greater flexibility in larger arrangements. Figure 4 shows a collection of samples rendered at the thresholds of certain part-conditions. For this, a custom software package was developed together with Christoph Zimmel enabling procedural bindings similar to BIM descriptions in a rigid-body-simulation-environment.

ARRANGING PARTS
In a further step, common attributes of buildings, like access, privacy, and floor connectivity were formally described as a mereological condition between two samples. These formal descriptions were tested and visualized via the implementation into a digital simulation environment. The goal was to visualize the design implication of specific part conditions. Therefore, the arrangements should be seen purely as “mereologies,” not as buildings but as arrangements and the multiplicity of one part-condition.

For assembling, this experiments explicitly do not lean on voxel-space-models. Voxel space as a discrete simulation model is highly efficient with little computational power. Especially in additive assembly voxels are highly practically organizing material with binary decisions, like glue or no glue. However, the excessive research of the last century into grids showed that spatial continuity at larger scales is mostly contextual disrupted starting with asymmetric thermal expansion coefficients of material composites to issues of ownership, territory, etc. Therefore, it would be misleading to assume a Cartesian space at the intersection of architectural and urban scale. The example of the twist-lock shows that...
at larger scales spatial continuity is dependent on specific interfaces. Properties, like stackability, are achieved by the particular design of parts. Here, discreteness as a compressed form of information ensures shareability. Not to be confused with aggregative packs such models establish order by sharing specific, not random data. Therefore, for first research sequences methods of assembly with point-to-point connections were chosen.

For the conduction of these experiments a software library was developed in CSharp, compatible with Unity’s API. The library allows the integration of physic simulation, protocols of assembly, custom data structures for storing and sharing data on part relations. To begin with the translation of formal discreteness into a digital design context, all studies build on rigid bodies simulation, which ensures a basic, geometrical boundary of each element. RigidBody simulations have several advantages. First, the use of collision detection can extend a typical modeling environment. The resistance between geometrical shapes encourages physical awareness, which allows a more intuitive modeling similar to traditional design practices with physical models. Second, simulating physical geometry reduces conceptual dependencies. Comparable to the twist-lock, strategies of disposition, the arrangement and consequently the overall form are dependent on specific design aspects of one entity.

Modes of assembly build on the following procedure: a part is accessible through the provision of a list of vectors, indicating connection points. These vectors are extensible to store additional information, such as facing directions, type of preferred connection, or state of a connection. Such information is then used to move and orient one part to another part. In a trial and error placement, the cases of geometric overlap are checked. By overlap, a further place-and-check sequence will be carried out. With this procedures, dense packs can be achieved, simply by beginning the placing at the first element and continuing the place-and-check sequence with spatial close and available connection points. A spatial nearest neighbor search is not necessary as the placement can jump from the points belonging to one part to the points of connected parts. Collision checks using a standard physics-engine, are today performative reasonable. The author tested here two libraries, the open source Bullet library, and the commercial Nvidia-PhysicsX engine. With both libraries the author reached up to 2,000 sequential collision calls with a pile of 2,500 objects per second on a standard laptop, using box colliders. Decomposition and combination strategies can be used to describe more complex shapes. Performative studies showed here that explicitly designed compound collision shapes are mostly much more efficient than generated mesh shapes using fracture algorithms or concave collision shapes.

Interestingly, figurations resulting from the assembly of the same type and number of parts are congruent in their characteristics. The form and sequence of distribution have less influence on the consistency of the overall arrangement than the design of the figure itself. The design of the figure can be considered on multiple levels dependent on the compositional depth of nested objects.

MEREOLOGICAL PARTHOODS
A compositional classification of samples into parts and wholes is digitally defined through the form of access. A digital part offers access to its internal composition. A digital whole is disclosed from any access to internal modes of compositions. However, since each sample is also a part of an arrangement, a whole strictly seen cannot exist. Therefore, a classification of a whole refers practically to a certain threshold of “wholeness.” The classification into parts and wholes describes foremost a directionality of access. The kind of access can be quantitatively measured through the mereological density of a part. Mereological density refers to the depth and access to nested objects. A high mereological density describes a low compression of information resulting in the accessibility to nested objects in the depth of its density. A low mereological density represents a high compres-
Figure 6

Top: Whole-to-whole relation. Aggregational figuration based on the outlines and mixture of different wholes only, left: arrangement of 2,500 samples with one type; right: arrangement from three different types of samples.

Middle: Whole-to-part relation, relating sun-insolation to part-orientation; rendered with floor plates only. Left: sun position Berlin, March 21st, 10.00 am, right: Berlin, March 21st, 3 pm.

Bottom: Part-to-Part relation; left: horizontal arrangement on one sample connecting two-floor plates; right: multi-level arrangement with three different samples, and a dominant ratio of sample one, rendered as floor plate connectivity.
Figure 7
Generated massing: mereological parthood condition: courtyard as a stair.

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forms a whole. The vertical street of the structuralist movement is here a good example, where the apartment is subordinated to the collected arrangement. Part-to-part conditions refer to parts in different wholes which influence each other and their dependencies. In the two compositions at the bottom of Figure 6 polymorphic considerations of one sample partially as floor or stair alters the patterning of the arrangement. By shifting the access to parts as stairs increases the vertical orientation of the figuration. Such a list can be extended extensively by considering the depth of parts and would be unfortunately beyond the scope of this paper.

Mereological design begins with the sampling of parts, the translation, and the extension of part conditions. In a careful mixing of several mereological terms accurate and diverse arrangements can be achieved. Naturally, any building consists of an uncountable number of part-conditions. It is not the aim of this research to represent the complexity of a building just through part-descriptions. Rather it offers a strategic possibility to navigate as a designer with and beyond bureaucratic means.

The research presented here can be seen as a transdisciplinary study introducing mereological aspects into urban design. Therefore, the research shows and measures itself on compositional qualities and their potential at an urban scale only. It shows how complex compositions can be articulated by a collection of part-to-whole relations. However, this also limits the current state of the work. To assess the value of this research, it is necessary for a further step to apply these considerations in an existing environment.

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