Mereological Tectonics: The Figure and its Figuration

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In a close reading, the term digital can be described as a mode of composition. Literally meaning the act of pointing with a finger (Latin: digitus), the digital is the ability to represent values as discrete.[1] Before computation, the art of counting, and calculus, the digital deals with the problem of how one can represent discrete entities from a continuous, analogous spectrum. First of all, the digital makes things countable. The digital does not refer to a specific way of making a single bit—the discrete vs. the continuous—but to the counting, listing, comparing, arranging, and joining of discrete figures. Like the digital, architecture too can be described as a compositional discipline dealing with the arrangement and joining of figures. Seen as part-to-whole condition, architecture copes with modes of assembly.

Above all in the field of material systems a renewed interest in methods of assembly can be observed. Recent research by the Center for Bits and Atoms shows that a material system, consisting of discrete entities, robotic assemblers, and hierarchical procedures of assembly allows an enormous up-scaling of structural dimensions by keeping the ordinary part-to-whole relation between strut, beam, truss, and space truss.[2] Research into jamming-based architectures[3] 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. Those new possibilities in the field of material systems result explicitly from an overlap of digital possibilities and modes of assembly. Differing from research into material systems, architectural research here considers the impact of digital practice on the composition of a building. Building on the insights in material sciences, this research focuses on the influence of compositional operations on the design of an architectural object. At the intersection between digital thought and architecture, we offer an exploration of part-to-whole relations in architecture through research by design. Specifically, we are interested in design strategies where the complicity between parts articulates the whole.

Precursors can be found in the early models of form-finding by Frei Otto and his team.[4] As ingenious models, Frei Otto's famous catenary studies computed mathematical equations through the behavior of their physical form in a complexity that was not possible to design using software at that time. When a physical fabric was constructed connecting generic metal nodes with threads, the resulting material incorporated an agency of calculation expressing the natural shape of the flow of forces. The idea behind form-finding was to optimize certain design goals against a set of design constraints. Form-finding as optimized force flow implied the default of a neutral shape. Associated with mathematical formulas, precisely this aesthetic has often been accused of being the absence of an artistic will. That is partly true: the shape results from a regular arrangement by a two-dimensional array of spherical nodes. However, this method known as form-finding can act as a meta-model for digital modes of assembly. Apart from the search for an optimized structure according to external influences, form-finding above all offers a digital description of a compositional whole. With form-finding, the design of a whole is described mainly by two things: a node and its arrangement, and the figure and its figuration.

THE FIGURE AND ITS FIGURATION

In a first step of this research, it was important to show that differentiated figurations can be designed through the repetition of discrete elements. Exemplary in Figure 1, the design of a figurative panel and the way of its arrangement led to distinct shell-like formations, intentionally comparable to Frei Otto's catenary models. In Figure 1, the generic, spherical node was replaced with a willfully designed figure. The arrangement was kept comparable to Frei Otto's structural calculation models: the designed panel-elements were arranged in a two-dimensional array (fig. 2, left). Like a textile, such an arrangement unfolds under directional force into a three dimensional shell-structure. However, as digital simulations with rigid bodies showed, these arrangements do not follow the mathematical shape of the force-diagram like the original shell-arrangements. Depending on the geometrical body of the panel-element, the resulting shells differed in the curvature of their overall shape. The interlocking and packing of panels based on the geometrical properties of the individual panel influenced the mass distribution and thereby the shape of the shells (fig. 2, right). Therefore, the material behavior of the shell became absorbed into the geometrical particularity of the discrete panel element. Translated into a particular aspect of one element, it was possible to edit and design the material behavior of the overall shell.

In a following design study (fig. 3), the arrangement, as well as the inherent quality of one discrete element, were articulated. Starting with a convex polygonal figure—optimal for nesting—the design of the figure evolved into a figurative space-frame. In this specific case, the digital simulations showed that, on one hand, linear frame designs with less material consumption allow more spatial nestings, and on the other hand, the asymmetrical design of partially closed and open sides promotes stiffer figurations through a greater chance of hooking and interlocking of elements. The final spatial figuration was intended to express the tension between light weight and massive appearance. Through the simulation of potential figurations, remarkable characteristics emerged. In following, these were used as external measures like the behavior of packing, stiffening, material consumption, transparencies, enclosure, and depth. Through the initially repetitive arrangements of one discrete element, specific aspects of the design of the figure became relevant. The relations in a pack between elements are specifically nameable as compositional qualities like stacking, overlapping, and interlocking. Here, material behavior is defined as emerging qualities of one figure in its figuration explored through diverse ways of assembly. So, material behavior turns into an organizational principle of One in Many. External behavior and ways of disposition can be comprehended as internal organizational issues of a figuration. In addition, the inner logic of the design of one figure becomes visible in the external characteristic of its repetition: the potentiality of its figuration.

Figure 1: Rigid-body simulation of four figurations. (Top) Figure. (Middle) Figures chained under drag force. (Bottom) Two-dimensional array of figures under drag force. Figurational aspects influence the shell form of the overall assembly.

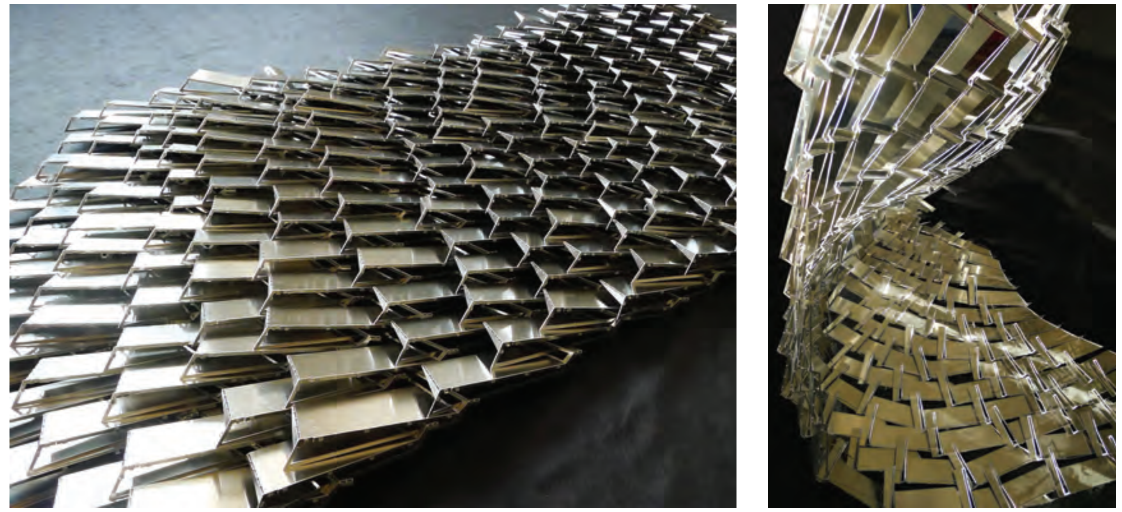


Figure 2: (Left) Repetitive arrangement of discrete panels; (Right) Their figuration as self-supporting shell.

For these experiments, an open-source design software "bRigid" for rigid-body simulations was developed.[5] Digital simulations of discrete bodies have several advantages. The potential lies not so much in the simulation of structural behavior, but in its unfolding towards an architectural design methodology. This amplifies the emerging effects of a discrete figure in its figuration, based on the materiality and geometrical qualities of one element. First, rigid collision detection can extend a typical modelling environment. Today's software packages provide quick and easy tools to edit design objects, beginning from morphological editing of polymeshes to seven-dimensional editing of building parts.[6] However, possibilities to develop and alternate the composition of objects are still rare. Here with a rigid-body simulation, the resistance between geometrical shapes encourages physical awareness, which allows a more intuitive modelling similar to traditional design practices with physical models. Second, rigid-body simulations reduce the need for abstract concepts of ordering and arranging. In the recent past, architects have described figurations compositionally as one form consisting of a number of components. The term component already includes the subordination under a predefined whole. In this abstract model, the panel or brick is determined and specifically articulated by the de-composition of the whole figuration. Following the abstract design of an archetype, the explicit components are oriented to outward positioned parameters. Regarding construction, such a function of subordination of parts leads to the problem that customized components are derived from an abstract archetype and not local conditions. Therefore, what seems to be customized cannot adapt to local tolerances and other unpredictabilities. Rigid-body simulations, simulating qualities of physical materiality, like mass or frictional surface resistance, consider configuring effects based on mass distribution, sticking, jamming, or wedging. The design of one discrete element influences and is expressed in the whole form. By this, the overall form does not derive from an abstract concept of distribution and subordination, but from inherent qualities of the discrete elements. The arrangement and consequently overall form are design aspects of one element. The figuration is a part of the figure.

ARCHITECTURE AS AN ORGANIZATIONAL MATTER

As a design model, such arrangements offer a new form of understanding of an inside and an outside as an organizational principle. Departing from cybernetics and constructivism, those arrangements build on the "postulate of independence and inclusiveness,"[7] where an inside describes the arrangement of a self-contained object, while an exterior characterizes autonomous objects as parts in an environment. In the recent history of digital architecture, one can find parallel concepts with both forms of organization, however in separated manner. The inside as the description of an inner organization is

Figure 3: (Left) Final arrangement; (Right) Figure-figuration design iterations.

comparable to the definition of the algorithmic in architecture.[8] Algorithmic strategies focus on the encapsulation of characteristics. Building on recursion, an algorithmic figuration is the result of hermeneutic procedures and, by definition, excludes external influences. The parallel digital strategy for the outside can be seen in the parametric as an external control of an inner organization.[9] Parametrics achieve great variety through gradual differentiation. Yet, one can criticize that heterogeneous wholes and contradictory complexity cannot be adequately addressed through the parametric mode of external abstraction. This design strategy accomplishes the complex distribution of design objects, but only of self-similar and therefore redundant architectural artifacts. So, this strategy lacks the possibility of specific descriptions of internal organizations.

Naturally, architecture builds on the theatrical tension between an inside and an outside. Beyond the physical separation of territories, this "double effect of inside and outside, between body and space, of enclosed and enclosing elements is the drive for themes of architecture." In its very essence, architecture is a simultaneous act of collocation and disposition, described by Oswald Mathias Ungers as "architecture's Janus-Face."[10] Learning from history, this opens the possibility to draw digital thought and its structure congruent to classical architectural knowledge as a new notion of an Inside Out as organizational principle. In a double folded description, a thing is nothing more than the difference between being-inside and being-outside, or "that which it comprehends and that which comprehends it."[11] Using this, one can turn the tension between an inside and an outside into an organizational matter as the difference between "that which is in and that in which it is."[12] In architectural terms, as recently theorized by Lars Spuybroek,[13] architectural design might consequently turn into an ecology of things, a "complex whole, a nesting of mobile parts finding each other on their own terms, grouping and packing together."

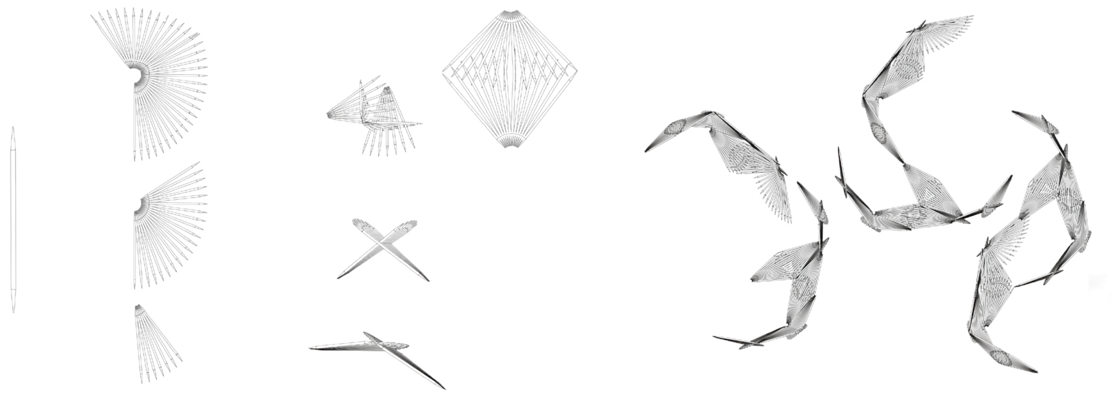
METHOD: MEREOLOGICAL TECTONICS

Here mereology becomes an important concept to advance the idea of digital compositions.[14] Mereology, as opposed to typology, is a methodological framework for designing an architectural object not through a reference to its content or form, but through the *resonance of its parts*. The term mereology derives from the Greek word meros: part. For the first time, mereology as such was mentioned by the mathematician Stanisław Leśniewski.[15] Not only considered formal logic, mereology is based on a historical framework in philosophy.[16] Recently, mereology has attracted new attention through a philosophical discourse on ecological thought[17] and a new interest in objects.[18] Mereological considerations focus on grouping and nesting of groups, their parthood and withdrawal from a whole, and an involvement in multiple wholes. A mereological approach can be seen as progress of the two main ideas, which evolved from the digital thought in architecture: the algorithmic and the parametric. We suggest here an overlapping and progression of both models, where the mode of assembly becomes the relation between different stages of inner and external forms of organization.

Each stage describes a certain overlap between internal and external forms of organization. The outcome is a result of the relations between every step. In each stage, certain aspects are specifically addressed, depending on their agencies. For example, crucial for the description of materiality might be stiffness in stage 1, speed of assembly in stage 2, reflectivity in stage 3, etc. As in Figure 5, one might start with a close reading of one element by grouping many of it in generic arrangements: points as clusters, lines as arrays, surfaces as fields.

The arrangements start as variations on Wassily Kandinsky's "Point and Line to Surface."[19] As an introduction to Kandinsky's formal teaching method developed at the Bauhaus, his book is also regarded as seminal for the modernistic mode of compositional classifications. Such a construction of geometrical elements via a hierarchical chain of points to lines to surfaces to volumes is still inherent in the clustering of commands in most of today's software environments. With the development of a globally acting building industry and the progress of planning instruments, these hierarchical chains have become encapsulated into the description of buildings and the parts of which they consist. However, the initially neutral, geometrical classifications developed into specific building managements: lines turned into steel-beam-skeletons, surfaces into concrete panels, and volumes into prefabricated living cells. O.M. Ungers already showed in his research on housing systems how the classification into lines, surfaces, and volumes produced specific characteristics of part-to-part connection, spatial partitioning, and modes of assembly. Geometric axioms turned into particular building parts, where internal properties determined larger aspects of the building. In three design studies, conducted at the Technical University of Berlin during the 1960s, Ungers designed large city-blocks as housing systems in steel, concrete panels, and prefabricated room cells.[20] Each study, based on a particular building element, elaborated

Figure 4: From wood stick to circular array to comb to volumetric shell.



specific characteristics of a building slab. However, by following the hierarchical order of modern geometry, none of the assemblies produced anything different or beyond the already pre-existing notion of a slab.

During the last 50 years, the building industry has progressed from the classification of building systems to an overall management of building parts.[21] Today, digital logistics can handle a diversity of products through interfacing digital representations of building elements. Therefore, digital representations amplify the parts of the building, which become more and more independent of the building as such. The modern mode of construction of building geometry depended on a subordinated nesting of building parts following geometric classifications. However, digital logistics can be described as chains of digital representations which work as interfaces between building parts.[22] Such representations are not globally linked to an absolute position on a grid but internally, chaining specific attributes of building parts. Consequentially, digital logistics demands discrete parts with discrete relative local positioning. If digital elements are discrete and concealed assemblies, wholes cannot be larger than their parts. With digital representations, the whole has to be encapsulated in the part: Form results from mereological complicities.

One example as an illustration: Considering a simple wood stick as basic element (fig. 4), the length of the stick and the length of its tip are relevant for the grouping of the line stick. Both properties allow its assembly into a circular array. The circular array as a group of sticks comprehended as one element can be described by the amount of sticks in one group. The amount of sticks in a group can vary. Groups with a dissimilar number of sticks have different qualities in their relation to the grouping of groups. Groups with a smaller number of sticks produce more volumetric, stiff figurations. Groups with a higher number of sticks produce flat, thin, and transparent surface conditions. Here, a three-dimensional formal language is articulated through the interplay of internal and external conditions of assembly. The design of the interplay articulates architectural effects: in this case, transparency and rigidity. An architectural formal language starts to evolve. The comprehension of the formulated group leads to a new element, this time not seen as abstract model of a point, a line, or a surface, but through its specific characteristics. Thus, the discrete geometrical element disappears; its meaning is embedded in the comprehension of the many as one.

Figurations of those circular shapes lead to a kind of surface shells. These figurations are described by their emerging architectural effects. Different arrangements will lead to complementary characteristics. The architectural effect turns into material behavior. The combination of volumetric and transparent surface shells creates spatial parts. In the last step, the comprehension of these spatial parts and their sequential arrangement lead to the design of the complex figuration as shown in Figure 7. The system is open for variations in sizes of the groups and different figurative interior and exterior situations without losing its characteristics. The arrangements might address certain aspects of building parts, like massive, structural parts or lightweight covering parts. The free space between the parts was here an external influence on the larger arrangements. The configuration of the inside and outside free-space is affected by its characteristics emerging from the interior arrangement logic. The exterior and interior spaces are designed without separation between inside and outside. The organization of the overall figuration was supposed to express the possible variety and complexity based on the mereological chaining of the initially chosen wood stick.

Even more important than the geometrical design of an object are its figurative characteristics. One can start with existing objects and recognize their geometrical characteristics and their influence in larger arrangements (figs. 5, 7, and 8). The design of one explicit element with distinct qualities becomes quantifiable through properties like its geometry, material, structure, or costs. The qualities reflect the possibilities of how one element can be connected to another. Qualities are selected, which create relevant effects in an architectural figuration. Geometrical properties with compositional

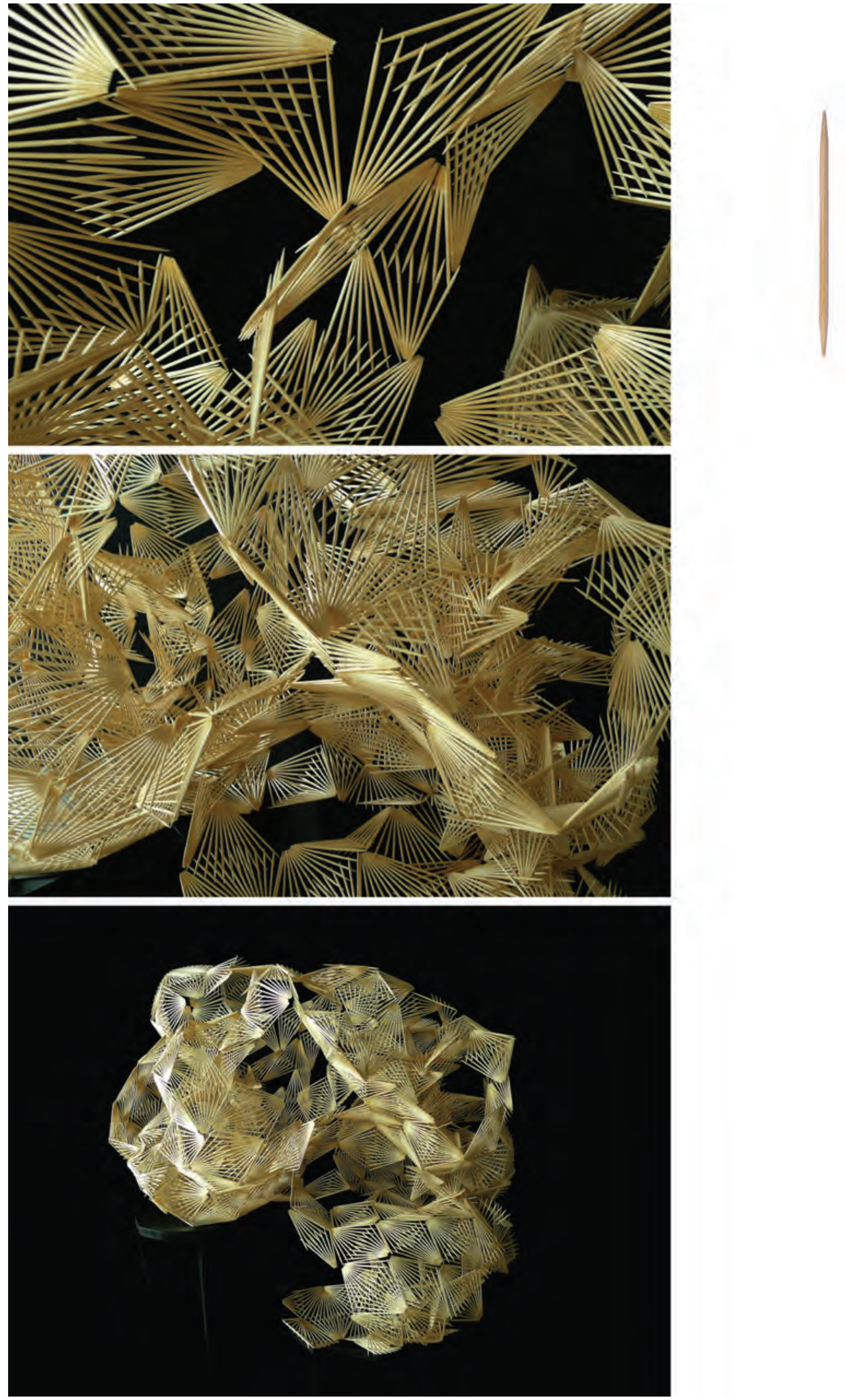


Figure 5: Wood stick figuration: From element to comb to shell to figurative arrangement.

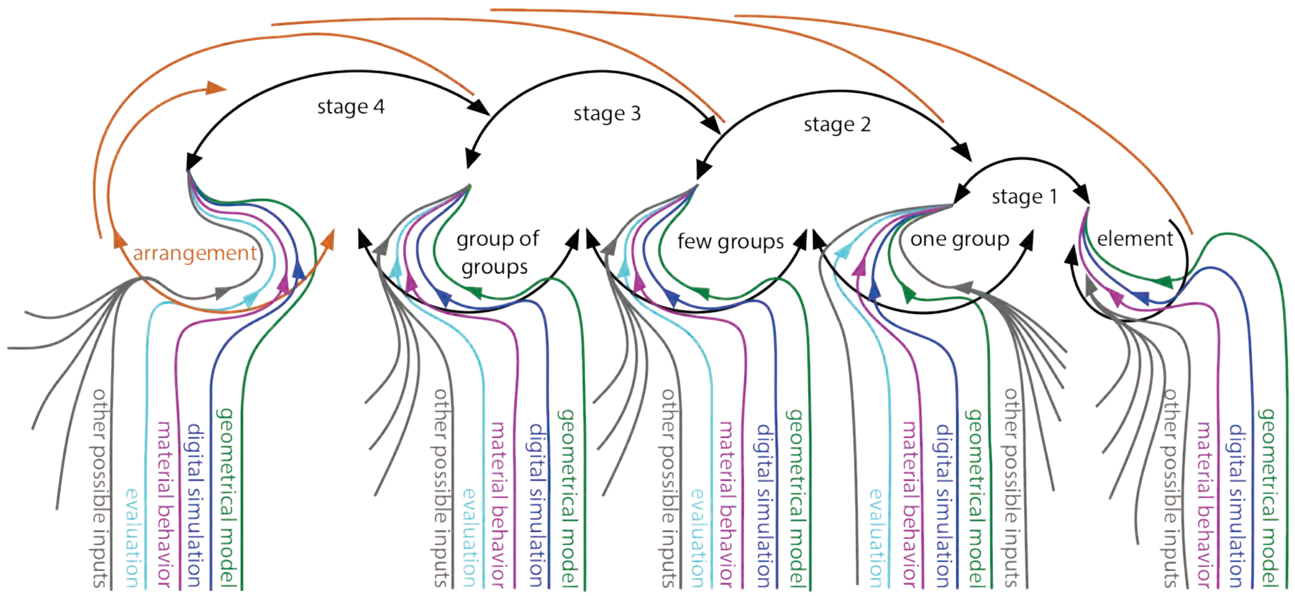


Figure 6: Schema: Mereological form-finding.

potential become apparent. They describe and manifest internal organizational principles. The complexity and richness are the result of the combination of elements by using their own geometrical properties.

Such a method understands "digital" not as software, as an extension of a technical device, but as cultural thought in matter. It becomes a method of designing transformed into the physicality of an object. As a schema of the digital itself, this circular process of transformation through design produces different characteristics by the merging of internal and external agendas (fig. 6).

CONCLUSION

The results show that one method can produce different outcomes expressing geometrical relations between discrete objects (figs. 5, 7, and 8). The research presented here can be seen as a transdisciplinary study introducing mereological aspects into architectural design. Therefore, the research shows and measures itself on compositional qualities and effects for disciplinary communication only. In other projects, the authors used the method presented to develop explicit building designs in a variety of scales. The method can include a diversity of styles, also in one design through the diversity of stages. Thinking about grouping principles and their stages allows imagining the building or large structure through its parts. This method can be used for an intervention in the existing architectural situation, for parts or the whole building. At the intersection between architecture and digital thought, research on organizational principles shifts the focus from complex materiality to complex compositions.

Architectural research focusing on techniques of the assembly of autonomous elements reduces the costs of fabrication and transport. Similarly, repeated but non-redundant processes will save time during construction. Simple techniques of assembly can be adjusted to simple tasks of robotic processes, but can as well be crafted by hand. Connecting smaller units makes many connections possible. This has an impact on the design of the structure, stability issues, or stress moments. Smaller units give us more freedom in design by up-scaling a number of compositional decisions, thus allowing new formal possibilities. The geometrical output is flexible in its variation, sizes, and amount of units. The design of the characteristics, rather than the form, facilitates the possibility of different various formal outputs without losing emergent geometrical characteristics.

The possibility of assembly, in a modern sense, typically the array—the assembly line—is here contained within the single building part. To put it in more general terms: the whole as a part for the part as whole. As a conscious design model, this effect can be described as mereological form-finding. Mereological tectonics offers the overlap of different part-to-whole relationships, as well as the achievement of architectural qualities through the friction and overlap of compositional plateaus.

ENDNOTES

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2. See the project "DMHSS: digital material hierarchical space structures," The Center for Bits and Atoms at MIT, Boston, accessed August 10, 2016, http://dma.cba.mit.edu/space_structures/index.html.

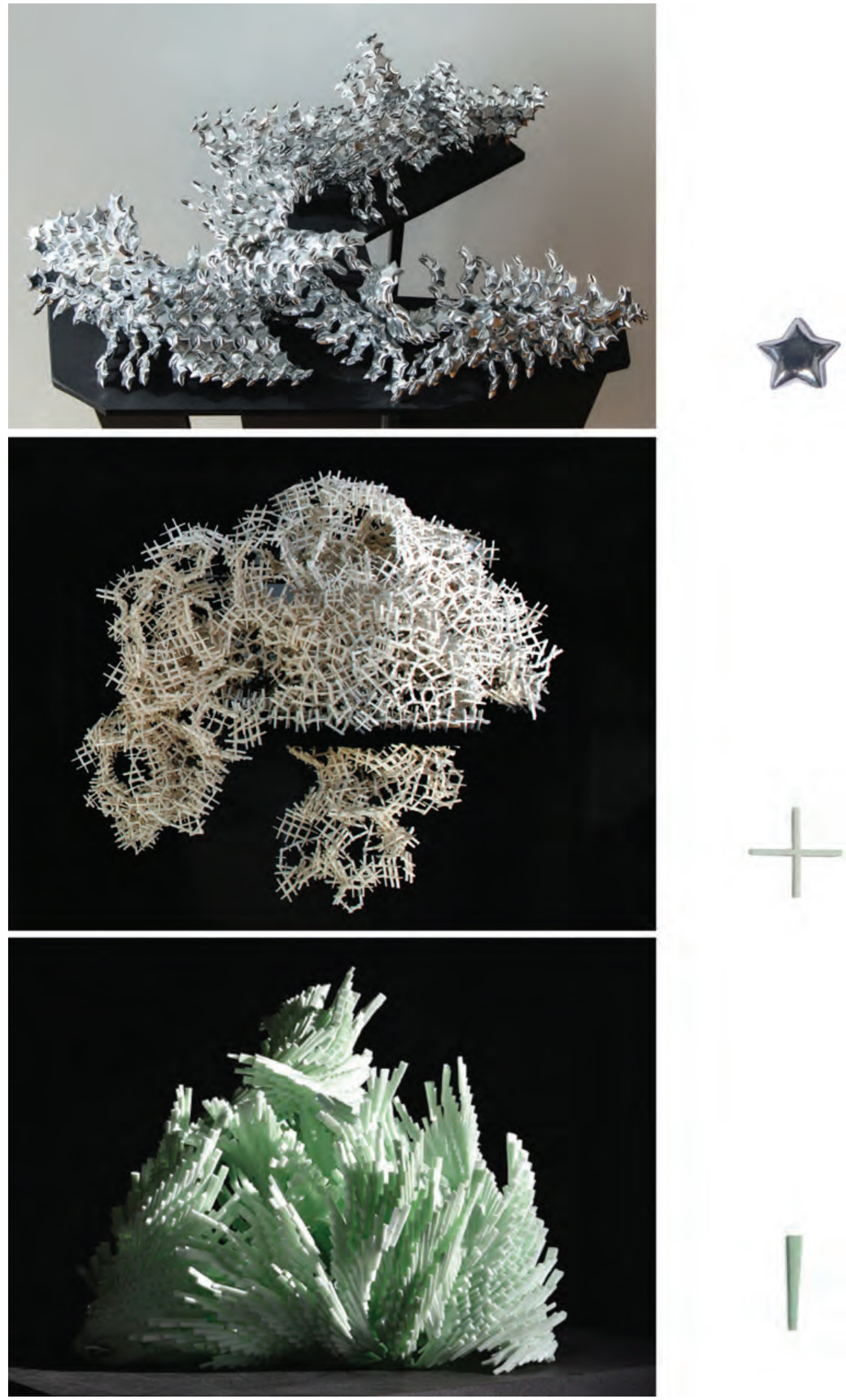

Figure 7: Figurative results of discrete elements considered as point.

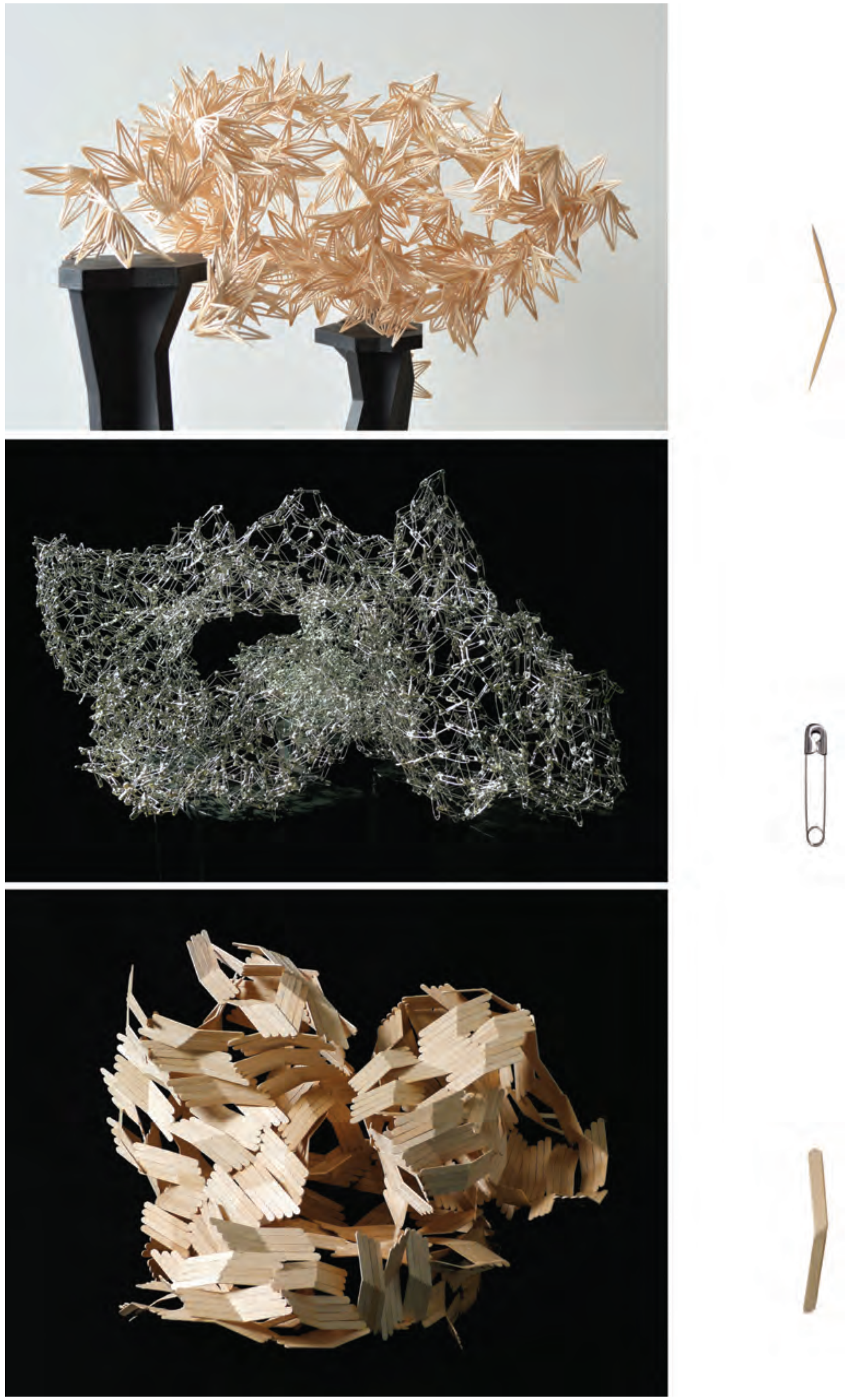

Figure 8: Figurative results of discrete elements considered as line.

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IMAGE CREDITS

Cover Image: Seminar: "Part-to-Whole Aggregates"; Instructor: Rasa Navasaityte; Student work by Yilmaz Dilber, Institute of Urban Design, University of Innsbruck, 2015; Photo by Florian Bucheger.

Figure 1: Seminar: "The Figure and its Figuration"; Vilnius Academy of Arts, 2014; Instructors: Daniel Köhler and Rasa Navasaityte; Student work by: Petras Vestarta and Lina Baciuškaite.

Figure 2: See Figure 1; 1:1 Mock-Up from Aluminium Plates.

Figure 3: See Figure 1; Student work by: Raminta Razauskaite.

Figure 4: Drawing by Rasa Navasaityte. 2015.

Figure 5: Seminar: "Part-to-Whole Aggregates"; Institute of Urban Design, University of Innsbruck, 2015; Instructor: Rasa Navasaityte; Student work by: Rüdiger Wäschl.

Figure 6: Schema by Rasa Navasaityte. 2016.

Figure 7: See Figure 5; Student work by Yilmaz Dilber (top), Röck Matthias Burkhard, 2016 (middle), and Tobias Stenico, 2013 (bottom); Photo by Florian Bucheger.

Figure 8: See Figure 5; Student work by Pazeller Lukas, 2015 (top); Maric Sanel, 2014 (middle); Stefanie Wallner, 2014 (bottom); Photo by Florian Bucheger.