THE ‘PARTICLIZING’ OF THE MATTER

Abstract

The ‘particlizing’ of matter (Kuma, 2007) and its simplification to elementary components is a complex act and a singular condition that comes from the arrangement of a series of distinct and separated elements into units. This paper will focus on the distinction of aggregate systems in two different types depending on their inner configuration: morphologically ordered and stochastic aggregate systems. For the first type, it is conceivable to identify a matrix; the second, instead, has a fluid behavior despite taking the characteristics of a solid material. Thus, this paper provides an overview of the state of the art for some architectures which combine aesthetics, statics, and sustainable technologies. There is a significant relationship between particles, matter, structure, and architecture. The method involves carrying out a review of the reading and critical analysis of the state of the art, the study of particle shapes by means of a software simulation, designing of a single aggregation unit, and, finally, outlining the aggregation process. The aforementioned process will be carried out through parametric and computational modeling. There is no hierarchy among the elements that make up such systems. They develop the ability to grow in a rhizomatic manner. Research contributes to developing the field of aggregate architectures, through the creation of an amorphous structure, the deploying of recyclable materials, the formation of lightweight architectures, and, above all, the design of a spatial configuration that is both structural as well as aesthetic, which works with the modularity of the physics matter.

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Keywords

Aggregate architecture, granular matter, aleatory architecture, rhizomatic architecture

Introduction

According to a systemic approach, the research project forms part of those technologies aimed at protecting the environment and resources with particular reference to the risks induced by climate changes and by CO_2 emissions. Aggregates, in architecture, can be defined as large amounts of elements in loose contact (Nedderman, 2005) or in the case of the present paper as a large number of embedded elements. Recent studies (Murphy, 2016) suggests that the assemblage of aggregate represents a sustainable method for the architecture. For this reason, preliminarily, it was performed a multi-criteria evaluation equally on the material selection used and the aggregation method. Assessment criteria were determined based on both specific sustainability principles and aesthetic qualities. The evaluation is based on the Analytical Hierarchy Process (AHP) (Saaty, 1982).

Goal	**Sustainable Material**
Criteria	Material availability Ease of processing/working Toxicity Raw material extraction RecyclingW Reuse Resistance to decay Fire resistance Maintainability Maintenance cost Material density
Alternatives	Option A—Reclaimed wood Option B—Plastic polymers

Table 1: AHP-material.

Figure 1: Radar chart-material.

A primary standing of aggregates lies particularly in enabling the realization of lightweight, recyclable, and reusable structures, which are important components in the climate system and play a key role in reducing climate change.

Goal	**Sustainable Aggregation Method**
Criteria	Recycling Ease of processing Ease of joining Reuse Resistance to decay Density/transparency
Alternatives	Option A—Stochastic aggregates Option B—Well-arranged aggregates

Table 2: AHP-aggregation method.

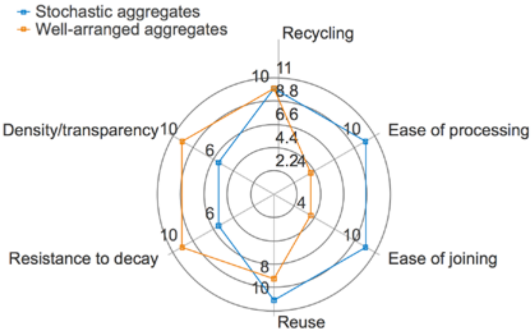

Figure 2: Radar chart-aggregation method.

The theoretical and conceptual framework of the research consists of the notion of fragmentation of matter into elementary components. Therefore, the question is if it is possible to design constructive systems, consisting of elementary aggregate components, that conjugate aesthetics, sustainable technologies and static analysis, coherently with the emerging forms of contemporary architecture. Research is focused on outlining the act of 'particlizing' matter. The term was coined for the first time by the Japanese architect Kengo Kuma (Kuma, 2007). Such a notion is translated into the specific action of making the material abstract and simplifying it into elementary components. It indicates a specific condition in architecture for which, the particles of that make up the material, namely modular parts both on large- and small-scale, are wisely aggregated to form a unity, although they remain separate from each other. It is almost tantamount to a sort of architecture of matter, thus the material is understood as a substance and not as finishing (Kuma, 2007). Such systems give rise to new emerging and amorphous forms. They are expressions of a solid link between particles, matter and structure, do not require any hierarchy and possess the ability to grow in a rhizomatic way. Studies into aggregates suggest that the theoretical foundation underlying the concept originates from some philosophical currents of thought latched onto the wish to 'fragment' matter to reach a kind of innermost, abstract and deeper side of it.

In several circumstances, Kuma affirms the significance, for an architect, of owning the control of each particle (Kuma, 2007). Actually, in a recent interview where he described the Water/Glass House, Kuma states "the idea of using wood boards as 'particles' or 'fragments' on the floor, on the walls and ceilings, is also the origin of some following projects where the main theme was the use of natural materials" (Alini, 2011, p. 26). On several occasions and on numerous interviews he explains the notion of 'relativity of materials'. In keeping with his idea, the choice of particle morphologies, i.e. particle size and shape with respect to the related parties and to the whole building, is essential for an architect. It is one of the most important choices. Kuma selected wisely, for instance, both the distance between each louver as well as their size for the Museum of Hiroshige Ando, a building placed in the heart of Tokyo. The choice was in accordance with the degree of transience that he wanted to give back to the user. Selecting the particle size meaningfully so that it is neither too big nor too small, allows the visitor not to perceive the matter as a mass. The research deals with this strand. According to Kuma, if the material is 'particlized', designing the right sizes, it assumes the characteristics of a rainbow. It becomes transient and thanks to the passage of light, even the particles have physical qualities, it seems to be made transparent. The solidity of the material, the continuity that appears on the outside, it is betrayed and fragmented on the inside, like an X-ray image. In this regard, the theoretician György Kepes suggests that radiography enabled humans to perceive the world in a different way. It made visible what appeared invisible. The transparency of the object depends on its own density (Kepes, 1969). It is about phenomenical and non-literal transparency (Rowe & Slutzky, 1963). Therefore, 'particlizing' matter is the device to make material abstract. It is made possible through a specific measurement system, the module. It is not the Modulor by Le Corbusier, which is thought of as an anthropologic, anthropocentric, and western module, but it is understood as a measure of material. These ideas are evident in the Japanese architect's most recent projects, like the Stone Museum or the Hiroshige Ando museum. What it is the so-called 'particlized condition' is a concept that goes beyond architecture.

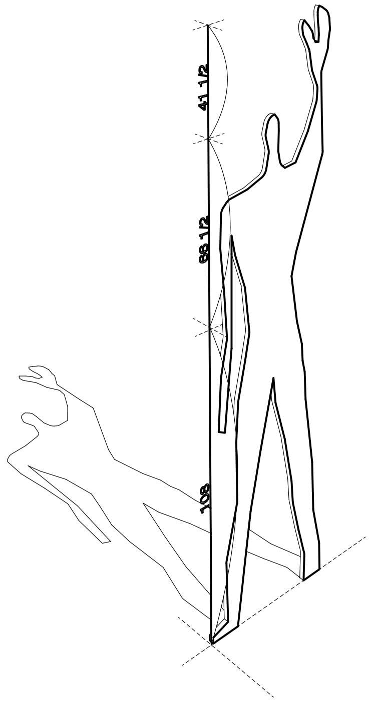

Figure 3: Modulor by Le Corbusier.

Paradoxically, it succeeds in making material more real, controlling the kaleidoscope of particles through the measurement of every component. This is the theoretical framework behind the present study. The contemporary practical outcome of this spatial conception and of the abstraction of matter. The objective of the study is, therefore, specifically aimed at the aggregate systems in which the sole trait d'union between each particle concerns friction or interlocking. Several theories have been proposed to explain the aggregate system. It is defined here as the combination of a series of distinct but aggregate components to form a unity. For each system, a morphologically ordered structure and a stochastic one have been defined.

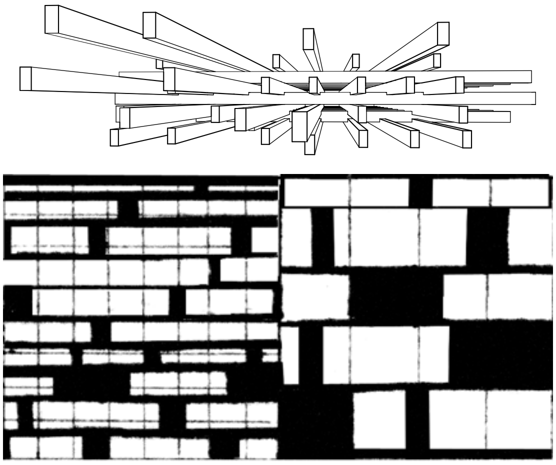

Figure 4: Apollonian configuration.

This is because prior research confirms that form in architecture reveals itself essentially in two configurations, Apollonian, measurement of order and Dionysian, measurement of disorder. For the former, it is plausible to identify a matrix, for the latter, it is rather unrealizable. For instance, the deploying of the Chidori technique enables the creation of a morphologically ordered system. It is a traditional Japanese wooden toy, consisting of cleverly embedded wooden sticks through detailed joints to create modular structures. The well-arranged system is generated by a clever modular repetition. On the other hand, the 'matter' generated by stochastic aggregate systems seems controlled by chaos.

It possesses the fascinating behaviour of a fluid when poured and, at the same time, the stable character of a solid material when it is an aggregate. Inspired by aggregate systems found in nature such as sand particles and ice crystals, aggregate systems in buildings have already been widely used. Sand is composed of convex particles, assume a very fluid behaviour, have a precise angle of repose and a conical geometric shape defined by the base's shape.

Instead, snow consists of dissimilar, asymmetric particles, and when it aggregates, it does not assume a conical shape and it appears more or less dense according to how compacted it is.

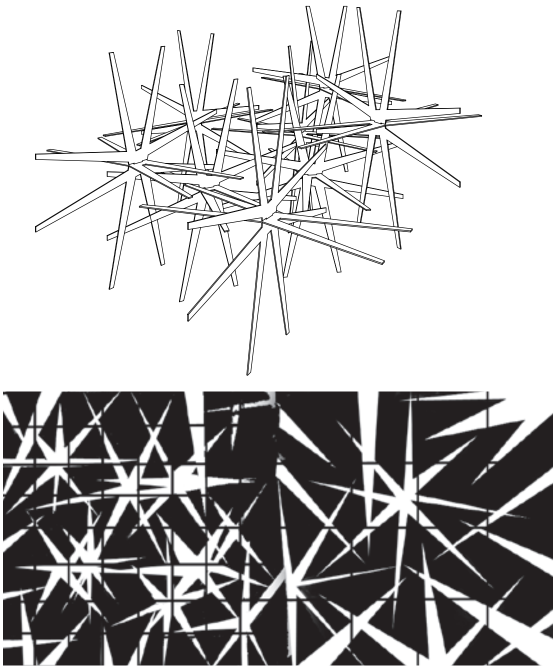

Figure 5: Dionysian configuration.

Actually, there have been a number of longitudinal studies and spin-offs involving aggregate systems, much is known about them. As the stone-filled gabion walls designed, for instance, by Herzog and De Meuron for the design of Dominus Winery in California's Napa Valley in 1998. The rock material was poured into metal gabions. It is an example of a disordered configuration placed inside an antithetically ordered structure. Furthermore, several studies agree that to design aggregate systems without confinement or without strings that increase traction, it is necessary to intervene on particle morphology, favouring the interlocking or the entanglement between the particles. Thus, several theories have been proposed to explain that when addressing the study of aggregate systems, it is essential to investigate different aspects to understand and improve mechanical behavior: the method of aggregation, particle distribution, interparticle friction coefficient, density, the angle of repose, superficial texture, particle shape, size, and materials. Within this paper, the aim is demonstrated that aggregate systems represent a constructive element arrangement consisting of elementary aggregate components that combine aesthetics, sustainable technologies and static configuration, in line with the emerging forms of contemporary architecture.

The major objective of this study is to investigate which geometries fix the most transparency and the relationship between form, size and matter. The porosity of an aggregate system, as well as its density, is the ratio between mass and volume and it is determined by factors such as particle shape, deformability, interparticle frictional forces, speed and height of the pour, deploying of robotic devices, and the design of stochastic as well as structured systems. For this reason, assuming to design aggregate systems without confinement which work only through friction and interlocking and for which factors such as friction coefficient are considered constant during the pouring, the study is exclusively focused on particle morphology, consequently, particle shape and size.

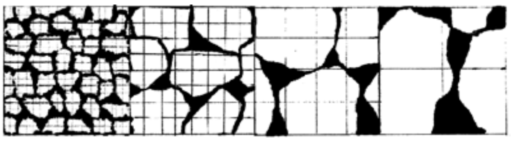

Figure 6: Wall detail in Herzog and De Meuron, Dominus Winery in California's Napa Valley, 1998.

Methodology

The methodology employed belongs to the field of emerging research, known as design-based research. It lends itself to the aim to refine the design of artefacts, to upgrade existing principles and promote new theory on the shapes of particles. Different methods are applied so as to verify a triangulation of the data. First, a review of the study on the current state of the art was carried out including the conceptual and theoretical framework on the articulation of the research problem. The second phase concerned the study of particle shapes by means of software simulation. The third phase consisted of prototyping. It was an iterative design phase, between the testing of materials and designing of shapes. Following this, the final phase was the evaluation and comparison between virtual and real models. In this paper only the first two phases are described, that is the revision of the state of the art and the simulation.

The results indicate that the deploying of a parametric software, the method of dividing the procedure into different phases and the experimentation on a flexible design allowed to perfect and improve the research. The academic community has extensively explored aggregate systems. In the past two decades, a considerable amount of literature has been published on aggregate systems. One of the first studies on the shape aggregates in architecture was by a student, Kentaro Tsubaki at Cranbrook Academy of Art in 1996 (Tsubaki ,2012). He used highly convex particles in ceramic particles, randomly poured. Similar experiments were conducted at MIT in Cambridge, MA (Gramazio et al,. 2016), at ICD in Stuttgart (Dierichs et al., 2012), or at Jaeger Lab in Chicago (Jaeger et al., 2016). So firstly, the state of the art was analysed focusing attention on shape, size, characteristics, constructive process, materials, and aggregation system. Subsequently, a simulation was performed using parametric software and particular plugins.

A large number of different particle shapes was designed, convex and non-convex shapes with variable dimensions. Convex particles such as Platonic and Aristotelian solids as well as highly non-convex shapes—one-dimensional rods and three-dimensional stars with a number of variable arms, aggregate rods with respect to different angles, three-dimensional stars joined to concentric spheres, bent particles and tensegrity particles. Every element is parameterised to speed up the analysis process. A box of fixed sizes was designed in CAD, with a length of 24 inches (61cm), with a width of 24 inches (61cm) and with a height of 12 inches (30.5cm). After defining the shape, the size and the volume of every single particle, the number of particles poured virtually inside the box was defined. This choice was carried out maintaining the ratio between the partial volume and the number of particles poured constant. With regard to the non-convex shapes, the simulation was first started for particles of the length of arms equal to 6 inches (15.2cm) and a cross section diameter equal to 0.12 inches (0.31cm). Afterwards, the simulation was repeated for lengths of arms equal to 12 inches (30.5cm). Regarding the convex forms, the simulation was started first for particles with an inner length of 6 inches (15.2cm), then with a length equal to 12 inches (30.5cm). Once the geometry of each individual particle was defined, the simulation of the poured begun. As an optimal condition was reached, different parameters were measured: the mass and the volume of the aggregation, the height, the width of the poured, and the critical angle of repose. The relative degree of porosity was obtained from the measurement of density, namely from the ratio between mass and volume. The simulation was performed also by applying a constant axial load to aggregate systems to measure the relative lowering. This research provides an important opportunity to advance the understanding of aggregates in terms of global design.

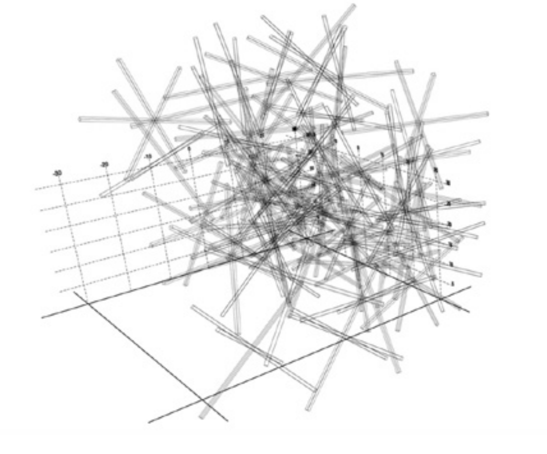

Figure 7: Non-convex particle shape.

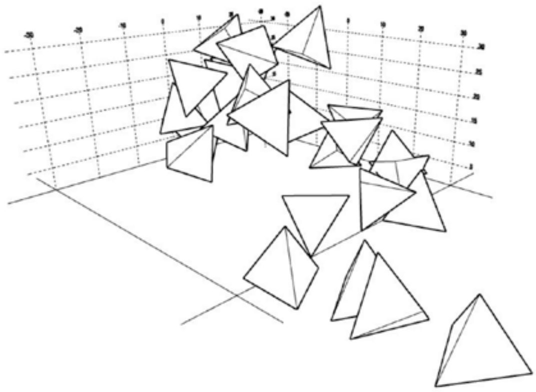

Figure 8: Convex particle shape.

Results

The state of the art survey led to the classification of aggregate systems on the basis of different aspects and features. The classification criteria referred to the morphological configuration, namely well-ordered or stochastic configuration, the presence or absence of confinement and strings to increase the traction. Likewise, it was suggested by the deployed materials, i.e., natural and artificial aggregates or aggregates consisting of programmable materials. A classification was designed according to the particle shape: convex, non-convex and double non-convex particles. Finally, a classification according to the interaction with the environment was created: non-actuating or actuating particles by means of systems like humidity or heat.

The result suggests that using convex particles in aggregate systems especially if the particle shape is spherical, involves a very fluid system. To the contrary, in the case of using non-convex particles, the aggregate system is not very fluid, and the angle of repose could reach up to 90 degrees. Furthermore, if a hook shape is employed, a very tangled system is generated and for this reason, it is difficult to disassemble it. What has been written up to now concerns the analysis of the state of the art. The second part is dedicated to the simulation phase. Using parametric software, what was expected was partly confirmed. On equal condition in terms of coefficient of friction and of cross-section sizes, in the case of stochastic aggregate systems, when fixing and normalizing the number of particles according to the whole volume, it was observed that, in the case of one-dimensional rods and three-dimensional stars with a number of variable arms, longer rods generate less density and so, more porosity. It emerged that particles having longer arm length generate a higher degree of porosity. This does not happen in the case of using particles with a convex shape. Platonic solids generate a highly dense and compact system. Surprisingly, it was unexpected instead that greater porosity is generated by the combination of concave and convex shapes.

Finally, ordered morphologically systems that are joined only by friction or an interlocking system, showed that the greater resistance to aggregation is returned by non-convex forms and that such systems can generate more porous systems.

Conclusion

The present study was designed to determine the effect of using aggregate systems in architecture. It is essential for the design of complex space devices such as aggregate systems, the deploying of a parametric and computational strategy, intended as a design tool.

The purpose of this paper was not to describe the aggregate system in general. Rather, the scope was studying the particle shapes that make up both loose as well as ordered aggregate systems and recognise which of them enables the achievement of a greater grade of porosity and transparency. It has been observed that the denser stochastic aggregate systems, usually, are related to the choice of a set of particles with non-convex geometry. And, choosing to assemble highly convex particles such as spheres creates a very aggregate system fluid. Consequently, in this case, it is necessary to intervene in the coefficient of friction between particles to increase the static resistance. The same considerations are applied to morphologically ordered aggregate systems. Unlike the stochastic ones, in the case of well-ordered systems, it is easier to reach a greater degree of porosity and resistance. Choosing to experiment with aggregate systems means working with very complex systems. Integrate aggregate systems with external devices such as ropes that guarantee traction make the management of the entire static system easier. In accordance with Kuma's theory about the relativity of materials, the experiment regarded particle shape and size to define a module, so that, after aggregation, the system is not perceived as a mass. No dimensions were found that were either too large nor too small. The aim was the design of an aggregate system as transparent as the material of which a rainbow is composed. So, the architectural synthesis of the aggregate system, whose realization is today limited to pavilions, installations and small objects, is perceived according to an unreal logic, subtracting from the intelligible perception system of signs. The outlook will be moved from simulation to experimentation. So, in line with the design-based method, it will be possible to have a further comparison of what has been investigated up to now and it will be possible to relate aesthetics with statics in aggregate architectures.

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