R.H. Crawford and A. Stephan (eds.), *Living and Learning: Research for a Better Built Environment: 49th International Conference of the Architectural Science Association 2015,* pp.943–952.

Coding randomness: accepting unpredictability in modular systems through the use of computation

Filipe Afonso[1] and Kirill Jedenov[2]
[1]*Chinese University of Hong Kong, Hong Kong, Hong Kong*
afonso@cuhk.edu.hk
[2]*The University of Western Australia, Perth, Australia*
kirill.delancastrejedenov@uwa.edu.au

Abstract: Through exploration of the dynamics of biological systems Kauffman (1992) found a 'magic region' of phase space where spontaneous organizations in nature reach a peak of complexity somewhat between periodic and chaotic arrangements, expressing a kind of random code. While the networks with which Kauffman was primarily concerned are biological, his analysis can be extended to architectural design. Positioned between too much and too little order, the moment of randomness is the medium in which new strategies for architecture could emerge. With these insights this paper introduces a series of possible housing structures that illustrate some of the key working methods available in digital systems such as 'generating' and 'compositing' taking as starting point computational strategies oriented to geometry and where the random factor plays a decisive role. Design can be inspired by this random nature, as nature is not designed with strict parameters, but it may evolve from a core of generative expressions of code. Architecture in fact could be conceived in a similar way the generative randomness develops into complex organisms, from the very bottom processes. This particular organizing principle - from code to shape - in Nature systems, acts along this paper only as an inspiration to the design process.

Keywords: Code; generative design; randomness; modular dwellings.

1. Introduction

The aim of this study is to develop a method for automated generation of residential building layouts using computation for graphics applications. This system intends to be adaptable to the constraints of low-cost modular construction industry. The project develops a computational tool to generate a network of three-dimensional dwelling structures derived from real-world functional requirements. The presented approach is an architectural tool that makes use of the idea of randomness to achieve an endless variety of computer-generated buildings produced under specific functional requirements.

It is an intention to show that randomness along the project is in some extent controllable even if the obtained results (dwelling aggregates) are in fact every time differentiated. Randomness in this project-exercise is not dissociated of intentionality; it is not associated with lack of control, arbitrariness or incoherence. This exercise contributes to a certain discussion about designing with architectural parameters and conditions, but also with degrees of freedom and resulting from the random arrangements – the generative through the random. Along the paper, the medium of programming using Python programming language will allow to model and control complex decisions and to refine a stochastic search process driving and disciplining that way the random experiments. As Littlejohn (2001), in order to survive within a dynamic environment, natural systems must be able to change, to be somewhat unpredictable: in other words, this could be referred to as morphogenesis. The same way, design methodologies constructed according to a certain degree of unpredictability are changing the way we think architecture, operating a fundamental revision in our mental processes. According to Vacas (2004) we are in front of a new kind of intelligence immerse in the new generations of digital technologies. The use of these processes represents a new way of thinking architecture in terms of computational process. According to these premises, the concept of randomness will be scrutinized, from his broader meaning up to more practical application in architectural design, interconnecting concepts of computation, generation of form and functionality. This paper will try to explore the concept of uncertainty, the role of the random factor applied to genesis of form in modular growth architectural structures. This study proposes an approach to computer-generated buildings using randomness as a motivation to achieve diversity on the architectural outcome, but departing from functional requirements common to the architectural practice. For that reason the initial modules Xx and Xy for developing the project include a concise list of functional requirements: number of bedrooms, social areas, amenities areas and approximate square footage (Figure 2).

2. References on modular structures

Few of the initial attempts of modular structures in architecture can be traced back to Durand (1813) and his modular elements grammar system that anticipated contemporary modularity in architecture and building industry. More recently, especially the past decades have witnessed the spread of modular construction into numerous applications in architecture, through the work of architects like Kisho Kurokawa or Moshe Safdie. By aggregating concrete modules in multiple geometrical configurations, Habitat 67 by Safdie (1971) was able to break the traditional form of orthogonal residential blocks, locating each box overlapping its immediate neighbour within specific rules of connection. Habitat 67 pioneered the emergence of unpredictable spatial organizations for residential buildings.

Habitat’s prefabrication technique was applied in Kisho Kurokawa’s Nakagin Capsule Tower, where a total of 144 residential modules are connected and rotated around a structural core of vertical communications. For Kikutake (1960), Kisho’s experiment on residential high-rise structures is a prime example of the Metabolism modular architecture, known for it's focus on adaptable and growing systems building design.title begins at 64 pt below the bottom of the citation header. The text on succeeding pages begins at 24 pt below the bottom of the header.

Many other examples can be found in the avant-garde movements in the 1950s and 1960s, such as the Archigram group, Yona Friedman and the Groupe d’Etudes d’Architecture Mobile, or through the work of Superstudio. These architects-urbanists pioneered the design of a three-dimensional urban structure as the framework of the new urban expansion of the postwar era reconstruction, many time based on the idea of modular transformation of the modern city (Sadler, 2002; Friedman, 1999; Lang, 2003).

These historical examples presented as pioneering experiments into the compositional power of modular structures present substantial limitations due to a certain drafting culture and the available tools for architectural design. According to Schlager (2000), the precise and accurate character of the referenced projects is reflected through practical response in a form of a building. Nowadays the fast achievement of a high level of compositional complexity is available with the introduction of new computational technologies, opening the possibility to simulate not just a single building solution but a vast number of building variations. The complexity of the assembly process, complex growth morphologies and modular variation and differentiation is possible with the use of advanced digital tool and computation oriented to graphic software.

The research presented in this paper addresses the limitations of design conception in the modular structures, analyzing several case studies in history, and proposing a new computational methodology for designing modular collective dwelling systems. At the same time borrows from such historical examples from the 1960s and 1970s the ever-present idea of functionality and adaptability to real scenarios. Especially the work of Ricardo Bofill in the built project Kafka Castle in 1968 is inspiring for this research study. The complex is an assemblage of prefabricated cubes, a three-dimensional composition generated by two mathematical equations resulting on an aperiodic design. This strategy based on a generative process that created volumetric overlapping and juxtaposition is in fact very similar in concept to the research project proposed along this paper. Along with the concern about the functionality, place and sensibility to local materials in the work of Bofill (Frampton, 1983) plays an important role in this paper, as explored in more detail under the section 6, serving as a real case study of acceptation of the unpredictability of code and mathematical abstract thinking applied to design compositions.

There is an emerging generation of designers and researchers making use of digital design tools and computation along with a new wave of software to support architectural design. The study of the interface designer/computing-machine led to the expanded application of digital tools in architecture projects. Looking closer on the recent developments in computational models applied to the generation of architectural spaces and specifically residential buildings, many researchers have explored algorithms for automated spatial allocation. As it is the case of the Boyd (2004) automated processes, that operate on combination of rectangular shapes in the plane or the Shaviv (1974) methodology for subdividing a regular grid creating residential units. To date, the application of spatial allocation algorithms has been limited to regular - based on orthogonality - architectural projects (Kalay, 2004). Harada (1995) introduced shape grammars to three-dimensional graphic applications and developed a system for interactive manipulation of architectural layouts. But seems compositional methods based on shape grammars have so far not produced complete building layouts even if implemented with optimization functions (Stiny, 2006). Other kind of advanced algorithms were developed for generating architectural freeform geometries and exploring form-finding strategies (Pottmann, 2007). However, none of these automated techniques is producing residential building layouts from specific functional requirements.

Recently many studies about modularity and self-regulating systems have been produced by architects like Michael Weinstock and the multidisciplinary office Ocean (Weinstock, 1998), Benjamin Aranda and Cris Lasch (Aranda, 2005), or the incursions into programming and modular structure by Meredith (2012). Most of the experimental work in digital architecture of the 1990s sought to create space through computational generative processes. But the wide spread of computational tools easily accessible to designers also led to generalizations about the configuration of modular architecture systems as solely an information system or a graphic composition, presenting in the majority of the cases, abstract scenarios far away from real implementation as residential buildings. This paper proposes a system versatile enough to adapt and configure to specific demands of the modular construction industry, producing low-cost-effective solutions (Figure 2). Under this main purpose the paper explores then a computational methodology for replication of residential modular typologies based on the power of Text Programming Languages for Visual Graphics Applications. As a future proposal, the section 7 discusses the development of a collaborative real-time platform between architectural design, final user and fabrication process.

3. Spatial vocabulary, maximum diversity dwelling system

The project featured in this paper, rather than presenting predictive housing structures, it questions the disciplinary boundaries by standing for the conviction that computation power can generate architecture outcomes embedded with functionality and aesthetic meaning. It revealed specially important for this research paper the pioneering work done by Johnson (2001), that comes from experimentation in pure computation applied to modular growth in biological systems. The role played by the unpredictable geometries driven by code and complex algorithm present in Nature system was an inspiration to explore compositing and generating techniques to develop collective housing structures. Examples of the evolved geometries or housing aggregates will be presented, which utilize the Xx and Xy dwelling modules as in the Figure 1 and in more detail in Figure 2.

The digital simulation of this architectural structures started by sampling randomly with the ‘Packing Script’. A script in Python programming language was developed to simulate the rules of connection between pre-established dwelling modules xX and xY, performing random alterations each time two modules are connected face to face. This allows explorations in incremental arbitrary directions and with random values at each iteration of the algorithm, without requiring the designer’s intervention or even knowledge of specific effects of the connection rules set. The geometries are reproduced with mutations of the connections for each new generation or iteration of the script (Figure 4). The idea is to change randomly the position between xX and xY’s each time a new element is connected.

The next step in the process was the modification of the script in order to permit selective growing by the user, picking preferred results from the evolving geometries. Artificial evolution of the housing structures is performed by first generating and displaying a population of simple random modules and then ask the user for interactive selection (algorithm with directional growth). This way more perceptually successful geometries, or more driven ones, can evolve.

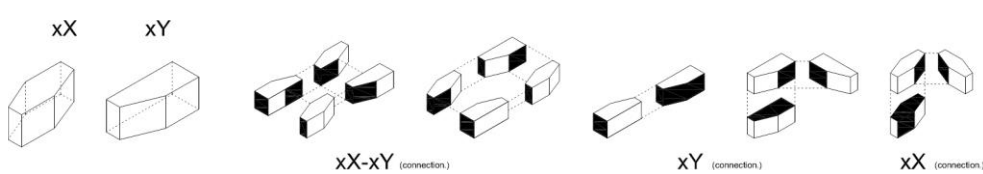

Figure 1: Contact possibilities between xX and xY elements: juxtaposition face-to-face using the rectangular connector surface. Due to the individual shape of the elements and the positioning between them, the assembly system achieves three-dimensionality.

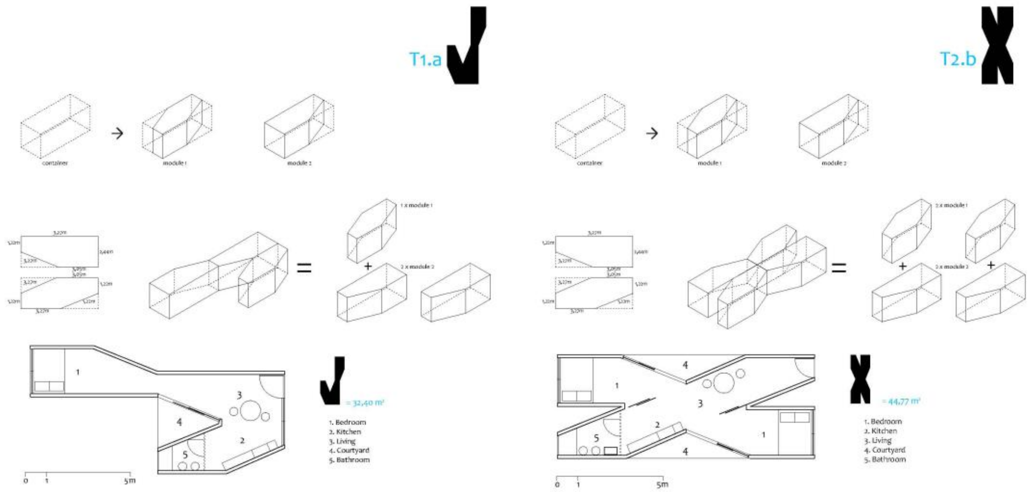

Figure 2: Examples of typologies T1 and T2, based on the combination Xx and Xy modules. The element xX was developed to represent in scale a small services module and xY was meant to have the minimum proportions of a living and/or sleeping compartment. Both modules are inscribed in a bounding box of 2,43(x) by 6,05(y) by 2,59(z) meters. The proposed modules pretend to be cost-effective, totally pre-fabricated, minimizing production costs and specialized labor on site.

4. Rules for packing

The characteristics of packing in this exercise, repetition of self-similar modular elements, provided the inspiration to tectonic assembly. This process simulates the connection of new units on each available face (empty). The ‘0’ and ‘True’ values enable the user to decide for an automatic and random growing or a more driven decision. ‘Init’ and ‘Add’ routines permit the user to introduce an ordered set of values to the modular connections. The experiments with systems of rules are:

4.1. Randomness

Phyton script implemented allows infinite possibilities of xX and xY modules packing. All the solutions obtained seem to be noisy. The algorithm creates random associations of modules, connecting face to face each generation of new elements (Figure 6). The result is a number of housing aggregates connecting the modules xX and xY at different orientations, where ´spatial compositions´ are generated randomly, without concern with structural stability, functionality or use of the interior spaces.

At the same time, this process and its formal result investigate a new aesthetic outcome in design in which random compositions and automatically generated three-dimensional patterns can be accepted as valid criteria. It also challenges traditional notions of functional occupancy, technology and tectonics and raises questions on how, for whom and where such architectural structures can be implemented.

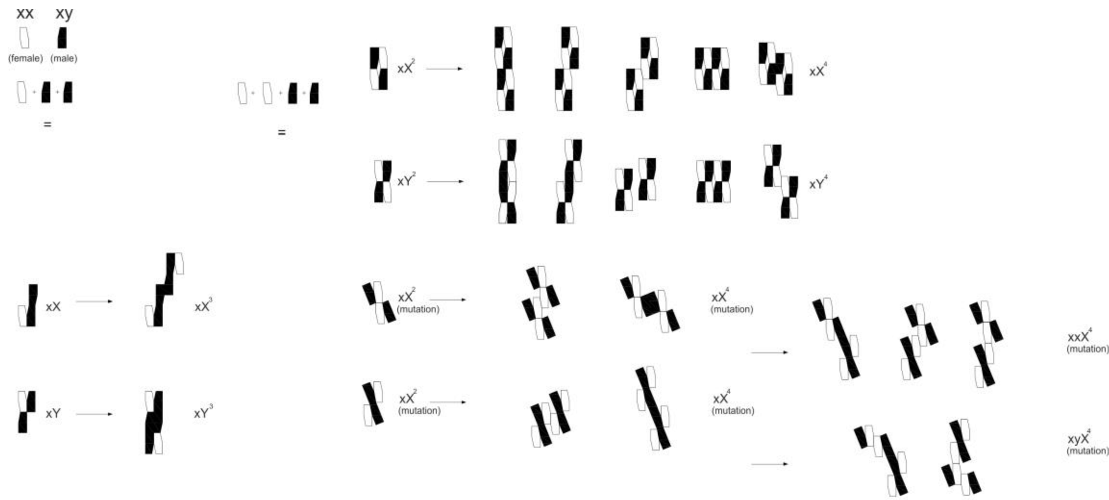

Figure 3: Grammar of connections between modules xX and xY. Few growth possibilities according to the face-to-face packing rule. Only self-similar faces may be used to perform connections.

4.2. Periodicity

Changing the script to be possible to drive the growing in specific direction, it means asking the user to select the faces where the next connections will be, we obtain quite different results. In this case the packing of modules will follow a specific pathway, bounded by the face-to-face only possible association. The modular association of elements forms more stable configurations. By stable it is meant regular structure not dissociated of intentionality (Figure 5).

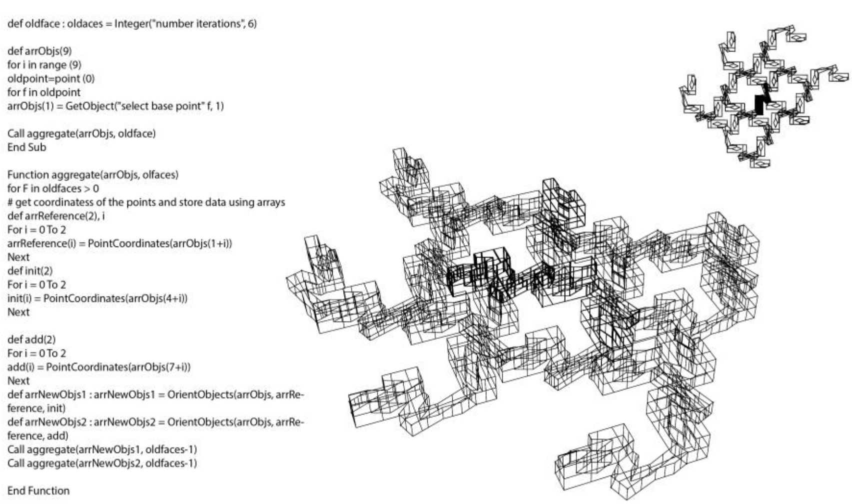

Figure 4: ´Packing Script', Python programming language script to generate random packing of modules xX and xY, using the graphical interface PyTopmod 2.223. Image of the script developed by the authors.

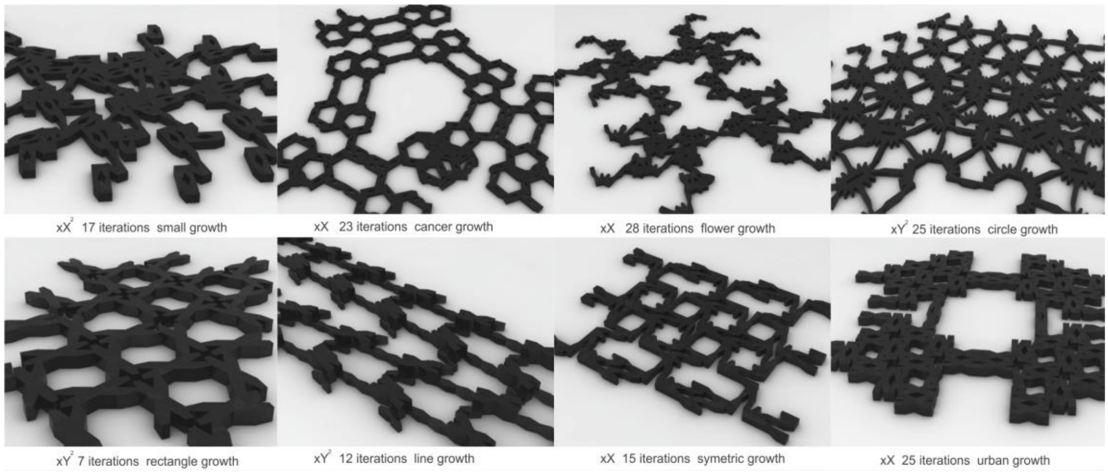

Figure 5: Diagram of evolved examples with periodic patterns. The images show different possibilities of growth by applying the packing script. The models are obtained by an active intervention of the user, driving the way xX and xY elements are packed together.

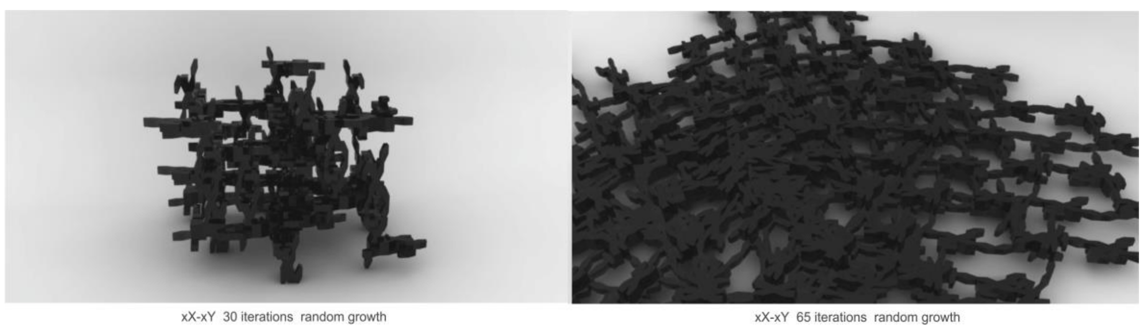

Figure 6: Diagram of evolved examples using aperiodic rules. The images show different possibilities of growth by applying random connection rules between xX and xY elements. The models are obtained with no intervention of the user.

The functionality of the script with periodic growth is shown in the following pseudocode (1):

Define Main Subroutine (1)
Get User Input:
Get the Module (array, the identifier of the starting geometry to replicate)
Get an array of 3-D reference points (with more than two points specified, then the function will align three-dimensionally the object between each other, similar to align or orient command in 3D graphic software)
Get an array of 3-D target points (this will be used to start the recursive function)
Get the amount of iteration (double, value for the number of iterations of the Aggregate function)
Start the recursive process:

Call the Aggregate function (custom function, inputs: the 3D module, the reference points, the target point and the amount of iterations)
End Main Subroutine
Define Function Aggregate (inputs: the Module as object, 9 points coordinates, and the amount of iterations)
Define 9 points for 3D alignment
Take 3D object as input and create 2 copies
#Aggregate Function Calls itself:
#Call the Aggregate function (inputs: the newly created objects, point coordinates and Threshold)
End Function

5. Random mutable rules

New rules may be explored in order to change de connectivity conditions between xX and xY, obtaining that way new sets of formal results and continue playing the role of unpredictability along the conceptual process.

5.1. Edge connections

Any node of physical connection between elements can mutate into a new connection expression. For example, changing from face to face connection between modules to edge connection. This allows for large changes, and usually results in a significant alteration of the final structure.

5.2. Vertex directional connection

Finally, if the new rule of contact is a vertex and a vector, the direction of growth can be adjusted by adding random coordinates each time the algorithm iterates, packing new elements xX and xY.

Other types of mutations could certainly be implemented, but these are sufficient for a reasonable balance of slight modifications and potential for changes in complexity. It is preferable to adjust the mutation frequencies to prevent the experiments from drifting towards large and "slow" forms without necessarily improving the compositional results of the aggregates as possible dwelling structures. Edge and vertex connections have immediate impact in the ability of the final aggregates to be structurally stable compositions and make the experimentation not viable as a functional architecture. As explored in more depth in the next section, a real implementation of these systems is desirable to test the ability of both the methodology and software to generate modular growth collective housing compositions.

6. Possible future, 1:1 scaled implementation

This research began with a real proposal to develop modular pre-fabricated houses. This way the paper also focuses on the rethinking of the standard housing typologies that designers, contractors and buyers can find in catalogues of modular pre-fabricated houses. We proposed other architectural prototypes and new ways to combine them, creatively, using the power embedded on the computational systems applied to design. The majority of the examples found in literature and transposed into architecture projects do not make a link with real implementation by the construction industry. The examples found, tend to be more exercises of design for the sake of building a computational process. Believing in a constructive premise, this system can be easily implemented in the construction industry, departing from simple modules - Xx and Xy - to produce creative, unpredictable housing aggregates or collective dwellings. Figure 7 shows a possible implementation in a real scenario, departing from the previous results based on periodic growth. This modular technology enables construction time to be reduced by up to half those of traditional building techniques while minimizing on site disruption and remaining significantly more environmentally friendly.

This project introduces an approach to a real liveable and significant environment. Its goal is not only to achieve a highly photogenic form of scenography, as observed in the majority of the recent experiments into computational modularity applied to architecture, but merge together functionality and the compositional power of computation.

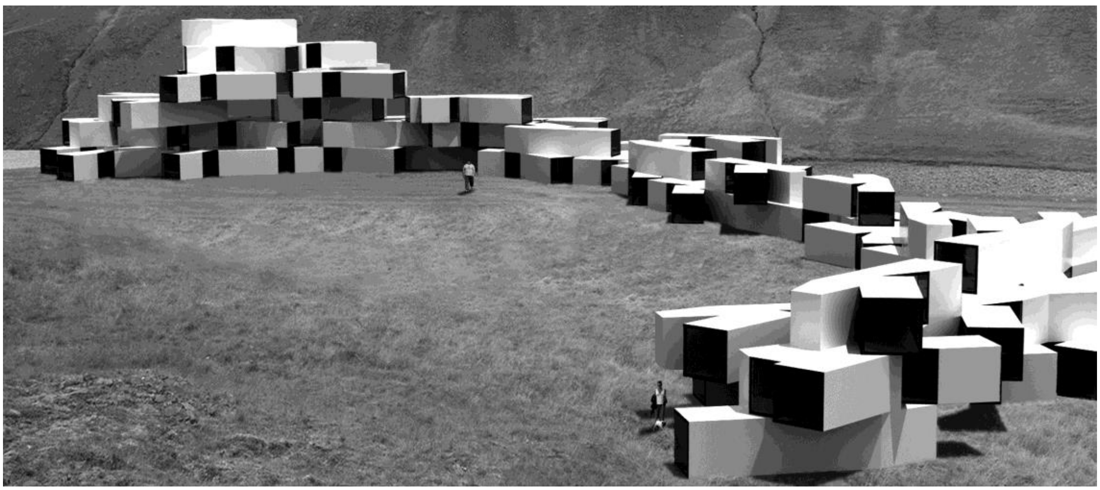

Figure 7: Possible future, implementation of a modular housing settlement in hypothetical real scenario.

7. Future directions and conclusion

As future work, there is a possibility to continue developing the algorithmic process under this research, by creating a real-time collaborative platform between designer, clients, engineering systems and fabrication. By using graphic software applications with COM technology that allows the implementation of code in Python for Applications (creating an software application opened in real-time to the inputs of all intervenient in conception process) it is possible to bring multidisciplinary performance feedback to the project. This work could lead to a data-driven approach to automated generation of modular residential structures, based on the inputs and functional requirements given directly by end users, clients, developers and technicians.

It is also possible to develop fitness functions that could restrict the growth system of the aggregates to specific conditions of the geographic site. Imposing site-specific conditions, physical limits, scale and density, we should evolve towards more controlled aggregations, due to selection of improvements instead of simply random mutations.

A large part of architectural research is presently measured not so much with forms and objects as with the conditions in which these forms can emerge. Thus stable structures no longer exist within the design process, or in other words stability is not an absolute given but rather, it derives from dynamic balance characterized by multiple and interdependent fluctuations. One of these fluctuations is in fact data. In this case data is related with shapes and is affecting directly the formation of architectural structures. The paper explored computing technologies that allow discovering, describing and unlocking unpredictable geometries, it also contributes to a radical change at the level of the conception strategies for design and architecture. Being part of the process is a key rule played by the designer.

Playing with code, based on digital design processes and random growth conditions, focuses on the procedures of architectural becoming. This method attempts to release the designer from predetermined formal or functional typological definitions. Departing from random decisions, the explored method bases the production of the architectural geometry as an expression of code or computation, allowing the emergence of architectural entities as part of undetermined experiments. It is hard anyway, to evaluate the formal consistency of the built architectures from the scripting techniques. A human decision, as well as an approach based on the functionality and real implementation of the modular structures as a residential space acts as a strategy to reduce a vast range of potential results.

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