International Journal of Architectural, Civil and Construction Sciences
ISSN: 2415-1734
Vol:11, No:7, 2017

Parametric Design as an Approach to Respond to Complexity

Sepideh Jabbari Behnam, Zahrasadat Saide Zarabadi

***Abstract*—**A city is an intertwined texture from the relationship of different components in a whole which is united in a one, so designing the whole complex and its planning is not an easy matter. By considering that a city is a complex system with infinite components and communications, providing flexible layouts that can respond to the unpredictable character of the city, which is a result of its complexity, is inevitable. Parametric design approach as a new approach can produce flexible and transformative layouts in any stage of design. This study aimed to introduce parametric design as a modern approach to respond to complex urban issues by using descriptive and analytical methods. This paper firstly introduces complex systems and then giving a brief characteristic of complex systems. The flexible design and layout flexibility is another matter in response and simulation of complex urban systems that should be considered in design, which is discussed in this study. In this regard, after describing the nature of the parametric approach as a flexible approach, as well as a tool and appropriate way to respond to features such as limited predictability, reciprocating nature, complex communications, and being sensitive to initial conditions and hierarchy, this paper introduces parametric design.

***Keywords*—**Complexity theory, complex system, flexibility, parametric design.

I. Introduction

THE nature of cities and how they survive and grow are not only accidental events, but also are the result and outcome of social forces, economic, technological and other forces. Today, all are agreed the fact that cities have a system with a complex nature and infinity effective factors. It can be said one of the main reasons for the failure of designing 20th century cities is the lack of understanding of the complex nature of them and the simplistic look to urban issues, as well as the linear relationship between its components. One of the issues arising from the complexity of cities is the developments and changes which are almost unpredictable. Today, the period of the formation of such developments in cities is much shorter than in the past. The tools that we apply to predict the changes and developments are slightly improved in comparison with the past, but due to the impossibility of predicting the future and its related factors - "Anonymity" - is the factor of causing the form [1] Mashhoudi believes that trying to change the face of a city is as hard as changing its culture and climate, and pre-designed cities like Brasilia and Chandigarh show this inability to adapt the environment well. Designing in a city and regional scale has a broader concept, so the result is not only based on a definite plan but also on flexible layouts and specific guidelines which will be formed on an ongoing basis with effective political and socio-economic calculations, and therefore it takes the shape of a process. The process is complex according to the nature of the system and cannot be implemented by using traditional linear methods. Now the question arises as to how a complex system like a city can be planned and designed with its myriad of complexities and unpredictable behavior. Many people who have different views provide solutions for the city and its issues.

To address the above question, this paper has two parts. First, studying the nature and characteristics of complex systems and then introducing parametric approach as a modern approach in urban studies, and finally, presenting parametric design as a responsive method and tool to solve complex urban issues.

Sepideh Jabbari Behnam is with the MA Urban design student faculty of Architecture and Urbanity department in Islamic Azad University Science and Research, Iran, Tehran (corresponding author to provide phone: +989370735282; e-mail: s.jabbari.b@ gmail.com).

Dr. Zahra Sadat Saeideh Zarabadi is now Associate Professor with the Faculty of Architecture and Urbanity Department in Islamic Azad University Science and Research, Iran, Tehran (e-mail: Z.Zarabadi@srbiau.ac.ir).

II. City Nature

A. Complex Systems

Webster defines complexity as "the state of not being simple" and complex as "a whole made up of complicated or interrelated parts" [47]. But, what makes a system complex? In other words, which qualities of a system cause to be called a complex one? The concept of "complexity" as a technical term applies to a system that is entirely different from the familiar linear system encountered in Newtonian physics. It should be emphasized that the concept is not difficult or complicated, but neither is it simple. Batty [2, p.8] recognizes the difficulty in finding a precise definition for complex systems, "which lies at the basis of any attempt to understand such complexity".

Complex systems exist everywhere in nature and in the world created by human beings, and first of all, it is a science which started at the Massachusetts Institute of Technology and the Los Alamos National Laboratory in New Mexico. Gradually, over decades, small groups of scientists from many fields of research started analyzing and discovering the common elements of complex systems, chaos, and emergence. It is the most multidisciplinary science of all and it can be called the same language for scientist in all fields to communicate and recognize parallel behaviors, and gradually to solve their more specific problems by applying their knowledge of the behavior of systems and the rules that direct them, expressing themselves in a kind of Esperanto understood by all.

Complex systems are ones in which numerous independent elements continuously interact and spontaneously organize themselves into more and more elaborate structures over time. There have been many definitions regard to various trends. A useful definition has been provided by Batty [3]. He states that "a complex system is a system that is composed of complex systems. This recursion makes considerable sense when we ponder systems such as economies and cities for their elements – individuals – clearly have the same order of complexity as any aggregation in groups or institutions" [2, p. 2].

Totally, each definition conveys an aspect of complexity. Batty [3] believes, while there is no single widespread agreement as to precise definition, there is a consensus about the definitions of the characteristics that a complex system displays. Therefore, instead of trying to coin a single definition for the term, an analysis of characteristics of complex systems can be attempted in order to develop a general understanding of the theory.

III. Characteristics of Complex Systems

Several people like Gleick [4]; Gribbin [5]; Durlauf [6]; Batty [2]; Cooper [7]; Portugali [8]; Wilson [9], have written about characteristics of a complex system, but Haghani [10], according to what have been used commonly and frequently in the literature, suggests that the following 12 characteristics of complexity are essential in the understanding of the theory.

A. Variety

It means a large number of components with dynamical interactions. According to Haghani [10], complex systems consist of a variety of subsystems or a large number of elements. When the number is relatively small, the behavior of the elements can often be given a formal description in conventional terms. Nevertheless, when the number becomes sufficiently large they cease to assist in easily understanding the system. However, although the numbers of elements are essential - it is not enough; for example, the grains of sand on a beach do not make a complex system, because although they are numerous, there is no interaction between them. This interaction should be dynamic and cause the system to change with time. According to Cilliers [11, p. 6], the most obvious example can be seen in the economic system of a city, as the economically active people in a city certainly comprise a large amount of elements, usually several millions. The various individuals interact by lending, borrowing, investing and exchanging money and goods. These relationships change continually.

B. Irreducibility

Another feature of nonlinear complex systems is irreducibility. While a complex system consists of a large number of elements, components, or subsystems, it cannot be reconstructed by simply adding its elements together. The notion that in general systems theory known as “gestalt” implies that system structure emerged from the parts, but that is not simply a process of adding up the bits to get the whole [2].

C. Deterministic Chaos (Duality of Determination and Randomness)

There are duality in behavior of complex systems, in other words, it is neither completely deterministic nor completely random; indeed, it exhibits both characteristics. This duality is termed deterministic chaos or complexity through rules" [7]. In complex systems, this sensitivity to initial conditions can be very acute during particular stages in their development - what are called phase transitions. When they are far-from-equilibrium, small fluctuations can push them into new basins of attraction.

While a simple deterministic system with only a few elements can generate random behavior, in a complex deterministic system, random behaviors are generated without violating the overall rules of the whole system [12].

D. Positive and Negative Feedback

A feedback could be defined as a channel or pathway formed by an ‘effect’ returning to its ‘cause’, and generating either more or less of the same effect. Feedback describes the consequences of change in a system. It means that feedback occurs where the behavior of an element influences the way other elements act or react, but through a series of relationships, the effect of its initial influence feeds back on itself [10]. Feedback can be divided into two qualitatively different types, what are called positive and negative feedback. A negative feedback loop represents a relationship of constraint and balance between two or more variables, whereas positive feedback in contrast to negative feedback is a self-reinforcing process. The increase in the values associated with one element in the relation is correlated with an increase in the values associated with another. In other words, both elements either grow or decay together. However, According to Byrne [13, p. 172], the significance of positive feedback – as opposed to negative feedback – "is that it is not boundary defending, but is likely to lead to boundary breaking and transition to a new phase state".

E. Sensitivity to Initial Conditions (The Butterfly Effect)

Engagement or positive feedback is highly sensitive to initial conditions. Through small and subtle change, you can change the output. Perhaps the best example for this chaos feature in complex systems is the "Butterfly effect" theory presented by Lorenz [14]. It describes how a tiny action such as the flapping of a single butterfly’s wing in the Indonesian coast, can be magnified through a month’s time of cause and effect process, resulting in a hurricane hitting Miami rather than its expected target of Fort Lauderdale, for example. So, when we have multiple interacting parts and basins of attraction, small changes in the initial state to the system can lead to very different long-term trajectories, and this is what is called chaos.

F. Limited Predictability

Laplace states that under the conditions provided on the behavior of a system and its initial conditions, behavior of the system after a given time could be predictable. However, this precision does not exist in real systems. There is always uncertainty about the outcomes of processes of change that originate from the bottom up [15]. According to Waldrop [16], when the number of elements/agents increases, it becomes even more difficult to predict accurately the outcomes of their interactions. Batty [15] states that the conception of the city as a complex system changes from one where we assume that all things about the system are ultimately knowable to one where this assumption is no longer tenable.

G. Emergence

Complicated and unexpected patterns and behavior emerge within complex systems with no apparent cause or design [16]. “Emergence” means that new systems appear with new properties, which are not to be accounted for either by the elements into which they can be analyzed, or by the content of their precursors [17].

H. Self-Organization

The capacity for self-organization is a property of complex systems which enables them to develop or change internal structure spontaneously and adaptively to cope with, or manipulate, their environment [11]. However self-organization refers to harmonic behaviors of a complex system without any up-to-down controls and disciplines.

I. Adaptability

In fact one of the most important aspects of complexity science is that the visible order is the result of proceedings and decisions which are made by peoples and agents. Self-organizing complex systems have the ability to adapt to new situations in their environments. Adaptation is the result of evolutionary processes whereby a system will simply not survive if it cannot adapt to new circumstances [10].

J. Interconnectedness (Synergy)

Interaction theory among different people, on which is based during the time, determines and defines the nature of the city; the different processes that gather people together that take place in cities can define many network groups. These physical and social networks as continue to expand willing to strengthen bilateral each other. Cities are dynamic systems and their spatial and social configuration is a result of an interaction of numerous effective factors.

K. Hierarchy and Levels of Scale

A complex system self-organizes by creating an ordered hierarchy of interconnections on several different levels of scale [10]. Fig. 1 shows a hierarchical organization at a number of levels, which is a logical representation of complex phenomena as systems of subsystems. A simple example of a hierarchic structure can be observed in a city street network [10]. Alexander [19] defined two types of hierarchy: the tree and the semi-lattice. Both the tree and the semi-lattice are ways of thinking about how a large collection of many small elements or sub-systems goes to make up a system with hierarchical structure, but only the latter leads to complexity.

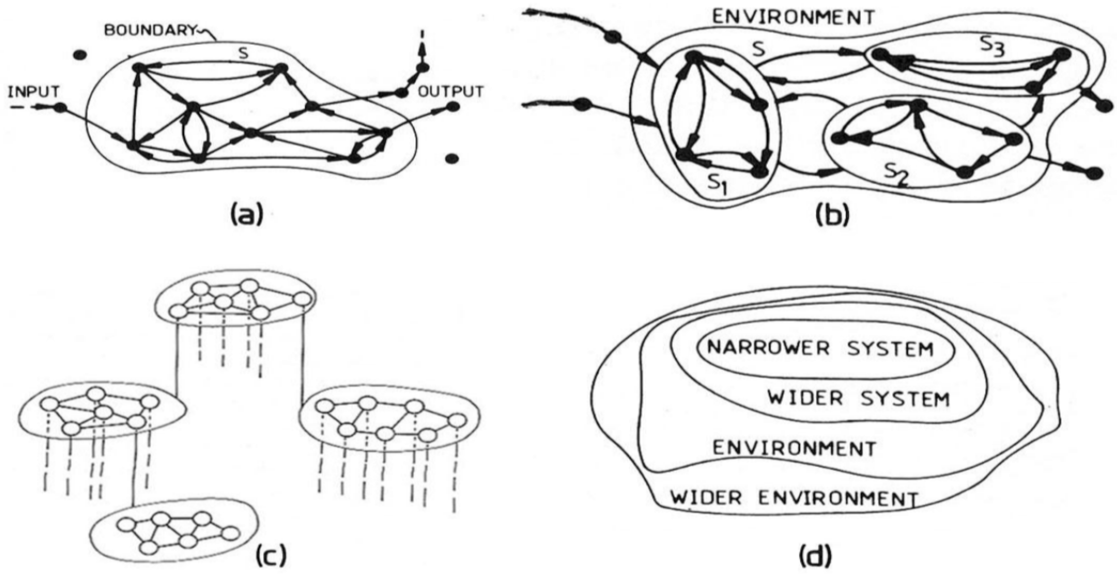

Fig. 1 Interconnectedness and levels of hierarchy (a) A subsystem, (b) a complex system of some sub-systems, (c) the hierarchy of complex systems within an environment, and (d) the hierarchical environments within a wider environment. (Flood and Carson, 1993, quoted in Haghani [10, p. 100])

L. Self-Similarity and Fractal Pattern

Fractals are both physical phenomenon and mathematical objects, exhibiting a repeating pattern that is displayed at various levels of magnitude, what is called scale invariance, creating self-similar patterns under magnification. Gleick [4, p.103] wrote, "Self-similarity is symmetry across scale. It implies recursion, pattern inside of pattern…. when a chaotic system is represented graphically, the resultant object is fractal". Symmetry across scales means that the patterns or images that appear at each level of scale in a complex system are self-similar to the whole.

IV. Complexity in Relation with Flexibility

Some of these factors are difficult to control and some of them such as topography, geographical location, climate, and social and economic factors due to their high relative importance are examined in most urban issues. Jacobs [18, p. 61] believes that the city is a mystery of regular complexity which has complex behavior. What is seen in the past, and especially in medieval towns, is a common growth pattern and self-organizing which was adapted to the needs of people over time, and on the other hand, technology growth rate was synchronous with people's needs. After the 20th century, as technology advances urban designs and linear models for these designs (designs from top to bottom) became common. This view considers a city like a machine which assembles definite, independent, predictable and controllable systems together. This view was first used by Tony Garnier in his industrial city and then entered in the Athens Charter [19]. Considering a city as a machine causes loss and death of contrast and diversity in them [3]. Jacobs is one of the first people protesting the vision of the machine city and she believes that cities should have known, understood and treated neither as a simple machine system, nor as a unorganized complex system, but should be considered as an organized complexity [18]. Variety of approaches such as bottom-up in order to respond to complex urban issues is discussed. Alexander believes that urban patterns and designs cannot be created or performed in the short term. He believes that step by step growth, which has separate activities in order to create larger patterns, is the basis. This growth has been slow and can create a society after so many years which have these patterns inside. He also believes that such large-scale patterns that can change the structure of the city or a neighborhood cannot be run with the help of a central power, lows or urgent plans [20]. One of the main challenges is how designs and proposed patterns should be and what the steps of production process design are needed in order to respond the complexity of urban issues and the city as a complex system.

De Neufivlle [21, p.70] believes that one method of dealing with complex systems is the management of an uncertainty feature and limited predictability of these systems, because a complex system with a small change can affect the long-term in regard to many aspects of a community. In a complex urban system this uncertainty can be seen in various aspects, for example unpredictability of economy, politics, technique and technology - what can be dealt with against uncertainty in a complex urban system is presenting flexible layouts [22].

A. Flexibility and Flexible Design

The term of flexible design, and particularly flexible urban design, although widely used by architects and urban designers, lacks a formal definition [23]. In recent years, many experts in a wide range of fields have been attracted to the concept of flexibility such as logic, economics, planning and construction [24, p. 165]. Flexibility is a term which is used in the design of engineering systems to refer to the ability of a system to deal with uncertainty [23]. Allen [25] believes that flexibility is a characteristic of a system which enabled changes with relative ease. The flexible design subject in urban design and architecture has been used in the field of housing [26]. Bentley [27] believes that flexibility is being ready to accept any possible changes in a system and also believes flexibility is a proper characteristic for a system in which uncertainty is one of its features. He assumes that ever increasing attention to the subject of flexibility reflects a growing awareness of the importance of uncertainty in the planning and decision-making.

Complex issues that require quick and adaptive responses, create the demand for flexibility in these systems [28, p. 167]. What is considered here about complex systems like cities and their designs is finding a designing system that is able to respond to uncertainty and changes in the step of a problem statement [29]. This means that flexible ways of dealing with rules and procedures which can provide system solutions instead of a final solution. For example, Alexander's pattern language proposed a structure with algorithmic formulas that has the ability to make numerous interpretations [20]. Beiro [29] states that flexible design, instead of the traditional fixed formula, is a series of solution designs for formulating a specific design problem which is defined by a series of specific laws. He also acknowledges that this particular definition for flexible urban design exclusively refers to flexible design for urban planning and must be able to meet the required variables. And finally, he claims two general cases for flexibility in urban scales; the flexible design and design flexibility. The first definition refers to the capacity of method, the design process to accept changes in problem, while the second definition (design flexibility) refers to the issue of whether the design can be changed during or after running or not. Finally, what is needed for flexible urban design is the third level of flexible design which contains the flexible design and design flexibility in tools and techniques of urban designing. Flexible design is a complex approach which should have applicability in different fields with various strategies in order to provide different solutions.

In order to design (either flexible or not), designers need to run multiple analytical programs, provide different solutions, and evaluate possible solutions before reaching a definite plan, and when faced with new problems or unwanted solutions, the proposed solutions must be revised from the first inevitability. This matter reflects how much phased design is important and how flexibility of designs can be useful for revising them in order to provide urban projects [30].

V. Parametric Urban Design a New Trend Toward a Flexible Design

Urban design is a process which includes problem statement, data analysis and evaluation of designs that are not necessarily in a chronological order. Design is not only the process of finding appropriate solutions to a problem, but also redefines the design problem and also it should be in a framework. Because of the scale and complexity of the nature of urban problems, a lot of factors must be considered in design process in order to respond to urban issues. Parametric design as a subset of a larger trend is generative design.

Davis [31] mentions two main approaches regarding to design and parametric modeling. In the first one, many architects have spent more decades to produce parametric modeling, and in other words, the process of achieving has taken a long time. In the second one, it is thought that since all definitions in the design parameters are derived from the architecture, so architects always have generated parametric designs. Such a definition of parametric design is expressed by Woodbury [32, p. 152] as well. He does not believe that parametric design is a new phenomenon, because compatibility with the field has happened in construction of building components many centuries ago. Similarly, [33], [34, p.18], [35, p. 54] have similar views about this subject. The first draft of the program for tool design was done in 1963 by Ivan Sutherland, in which a series of parametric functions is also proposed. In the 1980s, successfully achieving the development of digital technologies in the field of architecture was done in particular with regard to computer-aided design tools, such as two-dimensional software, three-dimensional modeling and digital animation and computer-aided design tools (CAM), such as rapid prototyping. Basically, by the application of these two tools simultaneously, designers are able to make the connection between design and production as well as integrating the entire designing process from design to manufacturing. This digital tool eliminates geometric constraints that existed in traditional design systems and through them, the use of non-Euclidean and complex geometry was possible. But this matter contradicted both production constraints and standard production and also mass customization with the concept of Fordism - mass production [36].

Despite all the achievements and development of the technology which had occurred by the 1990s with the help of CAM/CAD in the field of architecture, there is practically not any means to apply sophisticated computational and algorithmic methods in designing regard to the parameters of the production plan [37]. But since the 1990s, with the introduction and development of parametric design tools, this approach entered a new phase of the design. Thus, many architects began to design parametric and presenting their intricate and avant-garde designs [38].

The first attempt to urban parameterization using mathematical simulation was conducted in 1969 by Haggett and Chorley (Pooler quoted in [39]), and then GIS enabled designers to perform geographical calculations on larger scales. In 1976, Hillier proposed the theory of spatial layout and performed mathematical calculations on the morphology of places. Batty [40] began to examine the influence of limited aggregation on models of urban growth on a regional scale and studied the cellular automata and self-organizing features of urban systems. Recently, Koenig and Mueller [41] offered an application of Meyer and Land, and other modeling systems that are used today in the gaming industry, in order to optimization the modeling of urban spaces which provide more realistic scenarios of these spaces. Several definitions of parametric design are offered such as the Varaku definition. For defining parametric design, firstly, he begins to define the design term. He believes that design is a process for finding proper solutions to certain issues that eventually leads to the production of a product. According to this, he considers parametric design as a tool for designing based on parameters, variables and constraints [42].

Burry [33] introduces parametric design as a method that allows designer to define design scenarios according to the rules and basic databases in a reciprocating process by using certain parameters [43]. Also, he believes that this technique can be generalized and applied at all stages of the design, and it can be used in different situations and industries.

Parametric design has a feature of process design which its goal is performing different stages simultaneously and also considering various and effective factors as a parameter in a way that any tiny changes in each parameters causes production of new option [44].

Hanan Taleb [45] believes that parametric design turned out to be a complex process by defining variables and complex relationships and interactions between them. In other words, the parametric design approach is one of the suitable options in response to solving complex in urban problems.

As a result, parametric design is a kind of approach which uses algorithmic design rules for providing different solutions. As well, it can be broadly described as a design problem using defined variables. In other words, in parametric design systems, the specific parameters can define the design process, not an explicit form. Also, it can be said that, parametric design and modeling are object relations which are controlled by their variables [46, p. 7]. In addition, applying the theory of parametric design without having the right tools is almost impossible. As a result, this approach is also a thought which has been defined as an instrument that makes possible simulation of the environmental conditions on the basis of parameters which are involved with the context of space. Then, the possibility of making complex relationships among variables in the design process is created based on the direction and trend which are based on mathematical and algorithmic calculations. Other feature in the design process of parametric design is having the dependency of final design on initial condition, in a way that even with a slight change in any of the parameters; the final design will be changed. This system offers a set of solutions instead roof fixed design. However, according to the degree of complexity and unpredictability, each city requires more tools and methods for flexible urban designing. A system which could offer a set of solutions instead of a definite solution, in which adapting to the environmental conditions will be possible.

VI. Conclusion

Although there are different definitions and thoughts of various aspects of complexity theory, as to how urban issues can be answered remains highly challenging. Today, this idea that the nature of urban systems and its issues are complex is widely accepted. This paper, by providing a glimpse of the nature of complex systems and a better understanding of them through the features of these systems, tries to find a way to solve urban issues. The outstanding characteristic of these systems is their limited predictability. As a result, in order to design and plan for complex urban issues, it is necessary to define a system which has high flexible ability to be changed along with the environment conditions or initial system conditions. In this regard, parametric design through creating a flexible design process, which has both the ability to change and update information in all stages of design, and the possibility of involving a wide range of parameters and urban indicators, enables the designer to design a complex system, in which all components communicate and affect each other. Thus, in conclusion based on what was said, parametric design is a new approach in responding to urban complex problems.

References

[1] Mashhoodi. Sohrab, "Fluid foundations of urban design". Publication Processing and urban planning, Tehran, Second Edition, 2007,pp.111

[2] Batty, M. (2008). The size, scale, and shape of cities. Science, 319(5864) .771-769

[3] Batty, M. (2007). Complexity in city systems: understanding, evolution. Retrieved from

[4] Gleick, J. (1987). Chaos, Viking Penguin. New York, 193.

[5] Gribbin, J. (2004) *Deep Simplicity: chaos, complexity and the emergence of life*, London: Allen Lane.

[6] Durlauf, S. N. (2005) 'Complexity and Empirical Economics', *The Economic Journal* (vol.115), pp.225-243.

[7] Cooper, J. (2000) *The Potential of Chaos and Fractal Application in Urban Design*, Unpublished PhD Thesis, Oxford: Oxford Brooks University.

[8] Portugali, J. (2000) *Self-Organization and the City*, Berlin: Springer-Verlag.

[9] Wilson, A. (2000) *Complex Spatial Systems: the modelling foundations of urban and regional analysis,* England: Pearson Education Limited.

[10] Haghani, T. (2009). *Fractal Geometry, Complexity, and the Nature of Urban Morphological Evolution: Developing a fractal analysis tool to assess urban morphological change at neighbourhood level.* Birmingham City University .

[11] Cilliers, P. (1998) *Complexity and Postmodernism: understanding complex systems*, London: Routledge.

[12] J. P. Crutchfield, K. Young, in the Santa Fe Institute, Westview. (Citeseer, 1988).G. R. Faulhaber, "Design of service systems with priority reservation," in *Conf. Rec. 1995 World Academy of Science, Engineering and Technology, Int. Conf. Communications,* pp. 3–8.

[13] Byrne, D. (1998) *Complexity Theory and Social Sciences*, London: Routledge

[14] Lorenz E. (1963) 'Deterministic non-periodic flow', *Journal of the Atmospheric Sciences*, no.20, pp.1-11.

[15] Batty, M. (2005) *Cities and Complexity: understanding cities with cellular automata, agent-base models, and fractals,* Cambridge, Massachusetts: The MIT Press.

[16] Waldrop, M. M. (1992) *Complexity: the emerging science at the edge of order and chaos,* London: Simon & Shuster.

[17] Alexander, C. (2002) *The Nature of order: The Phenomenon of Life* (vol.1), California, Berkeley: The Centre for Environmental Structure.

[18] Jacobs, J. (1961) *The Death and Life of Great American Cities*, New York: Vintage Books, Random House.

[19] Alexander, C. (1965) 'A City is Not a Tree', *Architectural Forum* (vol.122), no.1-2, pp.58-62.

[20] Alexander, C. (1977) *A Pattern Language*, New York: Oxford University Press.

[21] De Neufville, R., de Weck, O., Frey, D., Hastings, D., Larson, R., Simchi-Levi, D., Welsch, R. (2004). *Uncertainty management for engineering systems planning and design.* Paper presented at the Engineering Systems Symposium, MIT, Cambridge, MA.

[22] McConnell, J. B. (2007). *A life-cycle flexibility framework for designing, evaluating and managing" complex" real options: case studies in urban transportation and aircraft systems.* Citeseerx.

[23] Gupta, Y. P., & Goyal, S. (1989). Flexibility of manufacturing systems: concepts and measurements. *European journal of operational research, (*135-119 ,432).

[24] Gifford, J. L. (2003). *Flexible urban transportation*.

[25] Allen, T., Moses, J., Hastings, D., Lloyd, S., Little, J., McGowan, D., Roos, D. (2001). ESD Terms and Definitions (Version 12). Cambridge, MA: Massachusetts Institute of Technology

[26] Gausa, M., & Salazar, J. (2002). *Housing and Single-family Housing*: Springer Science & Business Media.

[27] Bentley, I. (1985). *Responsive environments: A manual for designers*: Routledge.

[28] Sushil, & Stohr, E. A. (2014). The Flexible Enterprise: Springer.

[29] Beirão, J. (2012). CItymaker–designing grammars for urban design, architecture and the built environment. *Delft University of Technology, Faculty of Architecture.*

[30] Schön, D. (1987). Educating the reflective practitioner.

[31] Davis, D. (2013). Modelled on Software Engineering: Flexible Parametric Models in the Practice of Architecture. *RMIT University*.

[32] G. Ferguson, A. D. Woodbury, Urban heat island in the subsurface. *Geophysical Research Letters* 34, (2007).

[33] Burry, J., & Burry, M. (2006). Sharing hidden power-Communicating latency in digital models.

[34] Hudson, R. (2010). *Strategies for parametric design in architecture: an application of practice led research.* University of Bath.

[35] Gerber, D. J. (2007*) Parametric practices: models for design exploration in architecture*: Harvard University.

[36] Kolarevic, B., & Malkawi, A. (2005). *Performative Architecture*: Routledge.

[37] Monedero, J. (2000). Parametric design: a review and some experiences. *Automation in Construction,* 9(4), .377-369

[38] Yu, R., Gu, N., & Ostwald, M. (2013). Comparing Designers' Problem-Solving Behavior in a Parametric Design Environment and a Geometric Modeling Environment. *Buildings,* 3(3), 638-621

[39] J. A. Pooler, The use of spatial separation in the measurement of transportation accessibility. Transportation Research Part A: Policy and Practice 29, 421-427 (1995).

[40] Batty, M., & Densham, P. (1996). Decision support, GIS and urban planning. *Sistema terra,* 5, .76-72

[41] K. Scheidtmann, W. Fries, F. Müller, E. Koenig, Effect of levodopa in combination with physiotherapy on functional motor recovery after stroke: a prospective, randomised, double-blind study. The Lancet 358, 787-790 (2001).

[42] Varaku, E. (2013). *Computational Architecture: Focusing on perception and functionality aspects of urban intervention.* TU Delft ,Delft University of Technology .

[43] Steinø, N., & Obeling, E. (2014). Developing a parametric urban design tool. Some structural challenges and possible ways to overcome them. Architecturae et Artibus, 6(1), 51--57.

[44] Mitchell, W. J., Liggett, R. S., & Kvan, T. (1987). *The art of computer graphics programming: a structured introduction for architects and designers*: Van Nostrand Reinhold Company.

[45] Taleb, H., & Musleh, M. A. (2015). Applying urban parametric design optimisation processes to a hot climate: Case study of the UAE. *Sustainable Cities and Society,* 14, .253-236

[46] R. Woodbury, Elements of parametric design. (2010).

[47] https://www.merriam-webster.com/dictionary/complexity