EXPLORING THE COMPLEXITY. DIGITAL TURN TOWARDS GEOMETRY IN CONTEMPORARY ARCHITECTURE AND URBAN PLANNING

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ABSTRACT: The article examines concept of complexity in architecture and urban planning presenting proposal of systematics within the four methods describing complex forms: decomposition, deformation, dispersion and new complexity. The principles of each method are defined on general level. However, within each of the methods, more complex simulations, possible for unequivocal geometrical encoding, can be formulated. The methods can be applied for creation or analysis of both, abstract (2D and 3D composition), and real (specific building or city) forms. The article puts also under investigation application of these methods: for purpose of interpretation and systematics of contemporary architectural creation, development of new tools in design and for better diagnosis of city development principles. In recent years new tools enabling application of advanced digital techniques for exploration of unique formal solutions in architecture and new analytic methods for urban structures have appeared. The geometry becomes more and more universal language important for establishing bases for new digital techniques and interpretation of structure of complex forms in architecture and urban planning.

Keywords: contemporary architecture, urban analysis, fractal geometry, deterministic chaos, 3D virtual city models.

1. INTRODUCTION

Contemporary digital tools create new possibilities for developing buildings and cities. They so broaden aesthetic awareness. Using computers in the architectural and urban planning is already a well-established process. It became popular in 1980s and 90s. Initially, the application of new techniques boiled down to changing from analogue to digital tools. Although the new environment influenced quality and efficiency of work, it did not bring new values to designing, similarly to replacing a typewriter with a computer text editor did not influence the quality of content. Recent years witnessed a major change. New tools and possibilities of using more advanced digital techniques become popular which enabled wider use of computer's capacity. This has been followed by a search for unique formal solutions in architecture and new methods of analyzing the city space.

Catalysts of the new development in architecture include parametric modeling, NURBS and new prefabrication techniques: possibility of recording a digital form of a facility (CAD) as a sequence of instructions (CAM) recognized by CNC machines, dynamic development of techniques and growing accessibility of 3D print, etc. New technologies enable creating complex forms and reducing building cost. A sign of those changes is growing interest among young architects in programming, creating scripts (e.g. Grasshopper) and consequently more advanced form coding. Although the interest in complexity has been present in architecture since deconstructivism (1980s) and in its primary phase originated from philosophy and literature, digital tools are the driving force of the contemporary development.

However in urban planning, the recent tool is 3D virtual city model. Development in geo-information research, airborne laser scanning techniques (LIDAR), aerial photography analytic techniques, make possible automation and significant acceleration in process of generation virtual city models and new standards of encoding urban structures (CityGML) – cause, that accessibility and accuracy of 3D models is increasing in geometric progression. Sitting at the desk and staring at computer screen, we can easily browse virtual landscapes of most of world's agglomerations, using common free software of Google Earth. The applied tool extends possibilities of simple visualization. 3D city models are more often a medium for application of advanced urban analyses, impossible to execute without computer support.

Both, in architecture and urban planning, the subject of creation or analysis is complexity. However, geometry is universal code necessary for establishing bases of new digital techniques and for interpretation of complex forms. The article presents proposal of classification of this problem in reference to architecture and urban planning.

2. METHODS FOR DEVELOPING COMPLEX FORMS

The chapter presents proposed classification of possible methods for developing complex forms. Their hierarchy was created to interpret contemporary architectural projects. Methods of decomposition, deformation, dispersion and new order are described by the author in his PhD thesis [15]. The description is general enough so it can apply to various real or abstract spatial compositions, including urban structures. A form is understood as a specific shape, and the methods describe the construction process. Definitions of the methods determine pattern and scope of possible geometrical operations (measures). However, each method allows for more detailed simulations that provide for unequivocal, strict geometrical description. Presuppositions of those methods are presented in fig. 1, below. An example of compositions developed can be seen in fig. 2.

2.1 Decomposition

A set of possible operations within the mechanism of the method includes: break, crush, divide, separate, and fragmentation. The goal is to break the initial form or free compilation of various forms. The main feature of the method is purposeful breaking and far reaching transformation of a structure leading to new composition and aesthetic values. It is based on two essential measures: A) dividing the form and separating specific parts of it in a way which does not result from its construction (form organization logic); B) composing a form using independent parts – not by matching their shapes but by clashing them and allowing mergers. Decomposition can be used to rebuild the initial form (first A, and then B) or to develop a new form (only B). The aim is to highlight the heterogeneity of its construction, based on strong articulation of diversity of its parts and their geometrical independence. Measure A is presented in fig. 1. An example of B is simple overlapping of two regular mashes, which leads to a much more complex form (fig. 3).

2.2 Deformation

The method aims at plasticizing and transforming the structure of a form and at the same time preserving its indivisibility. Operations or terms typical for the method include the following: link, connect, fold, unification, etc. Presuppositions of the method are associated with mathematical topology. Composition measures concentrate on the form, treated as a whole, contained in one specific shape with all constituent parts subordinated to it. The construction process involves two measures: A) transformation of the initial form while preserving links between its parts; B) making the form of its parts – by their fluid merger leading to their mutual unification. The method can be used for rebuilding the initial form (measure A) or building a new form (measure B). The goal

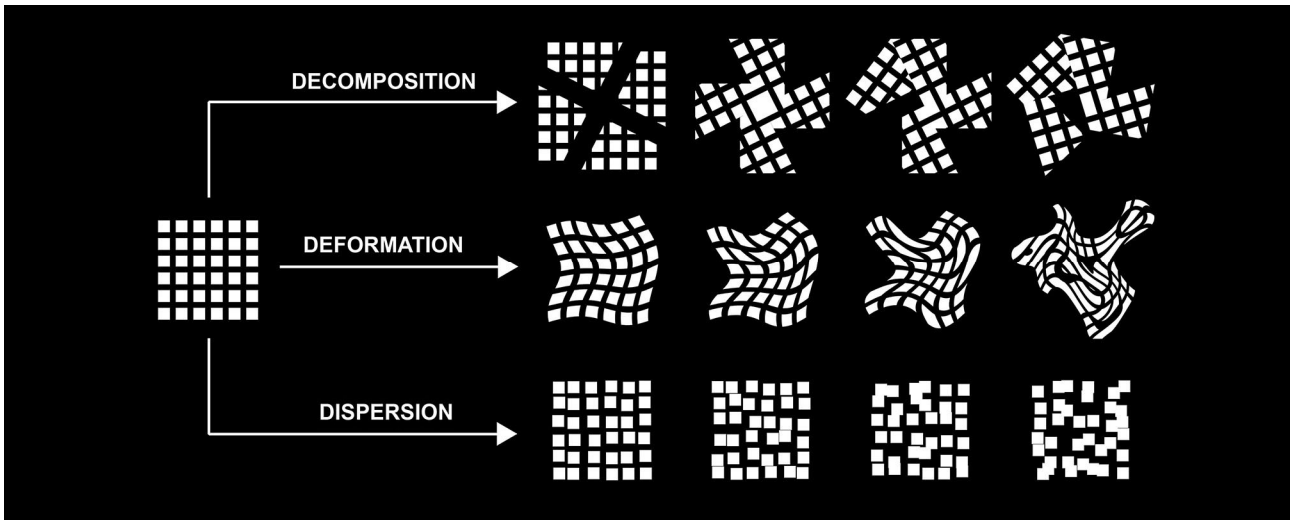

Figure 1: Schemes presenting methods of decomposition, deformation and dispersion

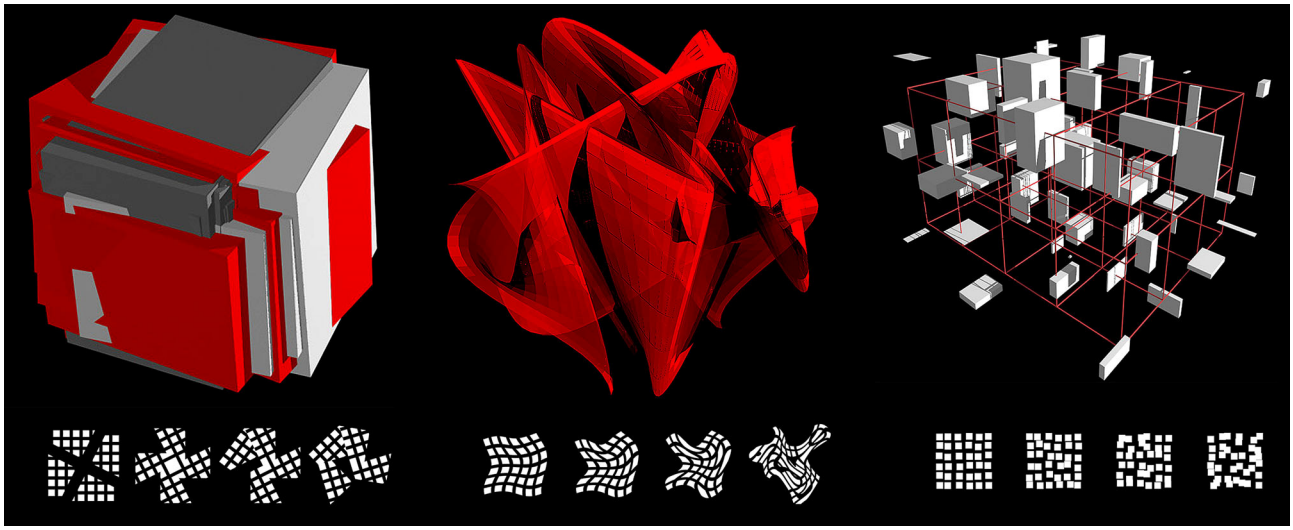

Figure 2: Compilation of schemes presenting creation of complex forms with examples of spatial arrangements. From left: methods of decomposition, deformation and dispersion

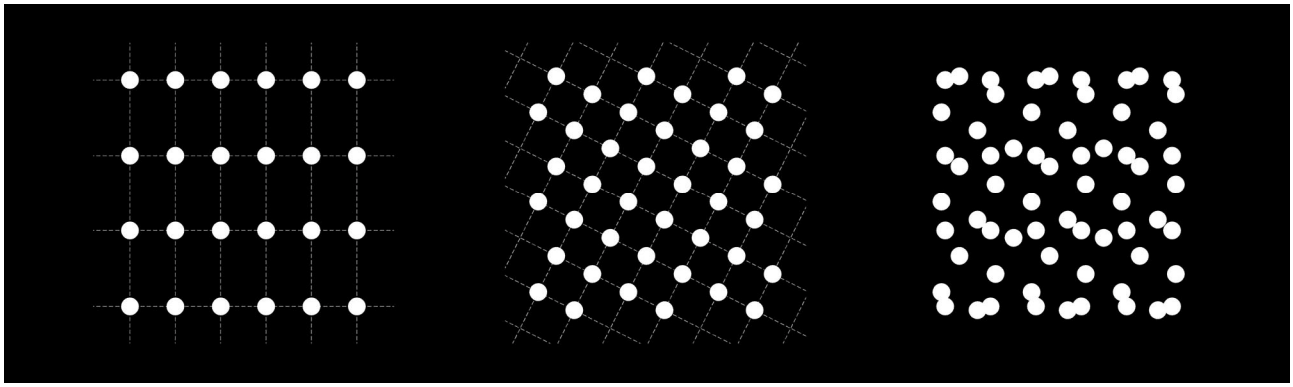

Figure 3: Example of decomposition method application: simple overlapping of two regular mashes leads to a much more complex form

is to highlight homogeneity of the form based on unification of its parts and their complete subordination to the general geometrical pattern of that form. Measure A is presented in a chart (fig. 1). An example of using measure B is the simulation presented in fig. 8.

2.3 Dispersion

The main feature of the method is using a random (stochastic) factor in the process of shaping the form. It is also necessary to distinguish a number of equal constituent parts. Their large number enhances the dispersion effect. Building of a form involves independent transformation of those constituent part (e.g. moving, rotating, changing proportions, color, etc.). Although only one and the same type of transformation is applied to all constituent parts, the way it is used (for each part) depends on a random factor. The method can be used for rebuilding the initial form of an orderly structure. By using dispersion, the structure undergoes gradual transformation losing its original clarity. This principle is presented in fig. 1. The use of a random factor can be measurable as a pre-set simulation parameter. Similarity of dispersed forms is an interesting issue. It turns out that two forms can be similar, although none of pairs of their constituent parts is identical. This has been presented in the simulation (fig. 4).

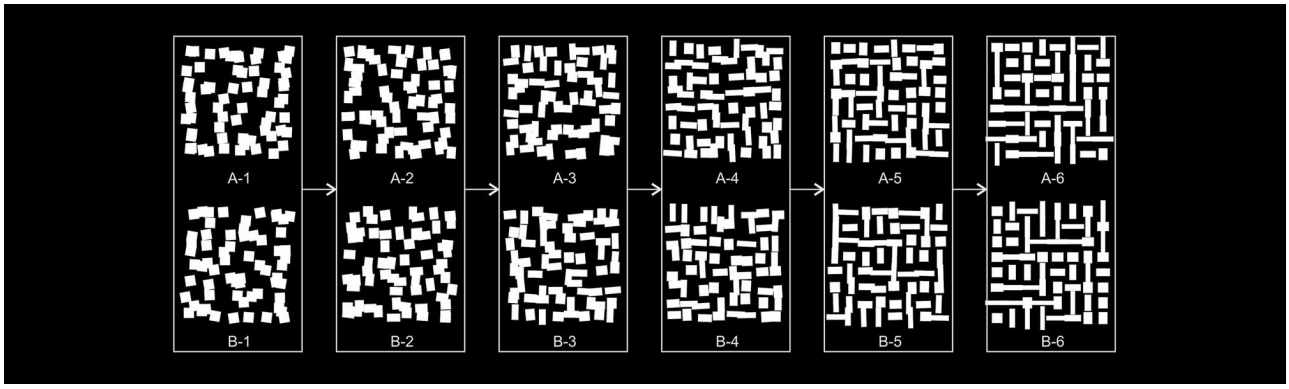

Figure 4: Similarity of dispersed forms

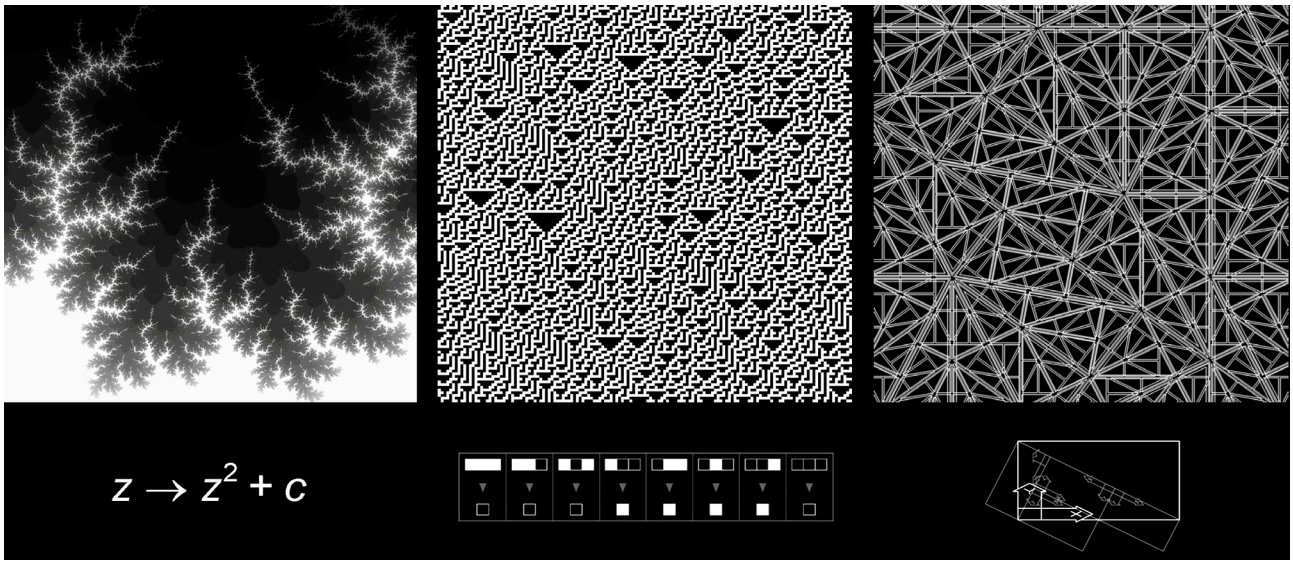

Figure 5: The method of new complexity: complex forms (upper part) are defined by simple rules (lower part): M set, 1D CA and IFS simulations

2.4 New complexity

The method aims at shaping complex forms by a simple process of formation. The principle of organizing (building) such forms is described as a system of higher order [15, 16]. The method refers to the mathematical theory of deterministic chaos, fractal geometry, and emergency. Rules can be expressed in different ways, for instance according to mathematical, fractal and emergent models. Each of the models defines a separate category of form definition. In the mathematical model, the form is defined using various formulas and rules. Computer simulations enable to observe basic systems of higher order at a purely theoretical level, e.g. Mandelbrot set (fig. 5a). In the emergent model, the process involves solely determining spatial relations and rules of mutual influence between particular elements of the form. An example is a simulation of cellular automaton CA (fig. 5b) [19]. The principle of the fractal model is based on transformations that can be described in the form of a simple geometrical pattern. An example of the above is a simulation using IFS [11] (fig. 5c).

3. COMPLEXITY IN ARCHITECTURAL CREATION

The chapter presents possible applications of decomposition, deformation, dispersion and new complexity methods for interpreting contemporary architecture facilities (since 1980s to present).

3.1 Decomposition in architecture

Deconstructivism is a clear example of the effort towards developing complex forms in architecture by using the method of decomposition. It started in the early 1980s, and matured in 1988 when the Museum of Modern Art in New York (MoMA) organized and exhibition of 'Deconstructivist Architecture'. The exhibition presented works by the then little known architects, such as Bernard Tschumi, Rem Koolhaas, Peter Eisenman, Daniel Libeskind, Zaha Hadid, Frank O. Gehry, Helmut Swiczinsky and Wolf D. Prix. The prevailing trait of works by deconstructivists is heterogeneity of architectural forms. In other words, they use a number of independent and intentionally unsuitable parts and divisions which do not result from a logical structure, as well as clashes and mergers of various elements. A rooftop remodeling above Falkestrasse in Vienna, designed by the Coop Himmelb(l)au Group in 1983 (fig. 6) is a vivid example of the above with its small scale and significance for a general architectural arrangement. On the one hand, Jacques Derrida's philosophy had a major influence on the development of the trend. On the other, geometry is the language of deconstruction. This can be seen in designs by Bernard Tschumi (in Parc de la Villette: clash between orthogonal networks of pavilions and natural landscape and deconstruction of cube) and Peter Eisenman (use of geometrical diagram). Deconstructivism continued developing until the end of the 20th c. as an expression of vanguard. Although it has finished, it still influences the contemporary architectural thought being a source of cautious or not cautious inspiration.

3.2 Deformation in architecture

The endeavor of contemporary architects aimed at larger complexity of forms also include designs focusing on fluid, flexible and streamlined forms. Instead of straight lines, various curves are used. Planes are replaced by complicated non-ruled surfaces. In the middle of 1990s, folding stood in opposition to deconstructivism in the contemporary architecture. In 1993, a special edition of Architectural Design was entitled 'Folding in architecture'. The editor was architect Greg Lynn. The article by the editor signified a new turn in architecture, and one chapter of the article was particularly telling: 'Curving away from Deconstructivism' [8]. The new trend developed under the influence of philosophical works by Gilles Deleuze. On the other hand, attempts made by architects to preserve homogeneity of form and combine various elements of the composition are deeply

rooted in geometry and mathematical topology. Möbius strip and Klein bottle are frequently referred symbols. Contemporary architects try to blur boundaries between notions considered to stand in opposition to one another, such as: interior and exterior of a building (e.g. Möbius House, designed by Ben van Berkel), or material and virtual space (e.g. Virtual Trading Floor, designed by Asymptote).

The idea of folding fits into presuppositions of the deformation method presented in the article. New computer modelling tools (e.g. NURBS) and new building techniques (CNC prefabrication) became catalysers for the architectural development in the field. A pioneer example of using new technologies is the Guggenheim Museum in Bilbao by Frank O. Gehry. Below you can see photographs of the museum with computer simulations by the author resulting from topological transformation of three cubes (fig. 7). Application of the deformation method also includes the blob architecture. An example of the above is Peter Cook and Colin Fournier's Kunsthaus in Graz (fig. 8).

3.3 Dispersion in architecture

Although the dispersion method is used for designing many contemporary architectural facilities, it is hard to define any wider ideological background for it, specific trend or style which would highlight the significance of stochasticity in shaping architectural forms. The issue was a subject of few research projects [e.g. 6, 17]. Example of using the methods is the Holocaust Monument in Berlin by Peter Eisenman. Within an orderly orthogonal system of 2711 concrete blocks we may distinguish irregularities (slight deviations from vertical plane and variable height of elements). Those irregularities give a specific aesthetic dimension of the whole facility. Dispersion is associated with natural conditions, perception of which is closer to a man. We may compare, for example, a wall made of various size stones, free surface made of granite brick, and tectonics of medieval tenement houses with similar forms of regular and repeated structure. The majority of method applications refers to the composition of facades. Randomness can be fixed in a building (e.g. distribution of windows and colors of materials in Sharp Centre for Design in Toronto by William Alsop) and may result from the way those facilities are used (e.g. mobile light breakers in National Library in Paris by Dominique Perrault). Yet another example of the application of a random factor is the Torre Agbar building in Barcelona by Jean Nouvel. Its external concrete shell is perforated by 4400 random square openings. Additional layers are placed on the main construction, including corrugates steel sheet cladding of variable colors (from red to blue) and glass panels as light breakers (fig. 9).

3.4 New complexity in architecture

The development of forms according to the new complexity method is something new in architecture, and searching for possible applications in its early stage. However, inspirations derived from the mathematical theory of deterministic chaos and fractal geometry already appeared in the output of several architects as well as publications by architecture critics [5] in 1990s. For example, the design of a new opera house in Cardiff of 1994, American architect Greg Lynn used a method which he described as 'branching'. Branching referred to fractal geometry [7]. However, there is a difference between inspiration and application. We are able to provide only a few examples of architectural facilities developed, where high complexity results from a deterministic process. It is also important that the specific nature of designing such processes and forms changes our understanding of creation in architecture.

One of preliminary examples of new complexity being applied in architecture is a multifunction complex of buildings at Federation Square in Melbourne designed by Australian architects Donald Bates and Peter Davidson in

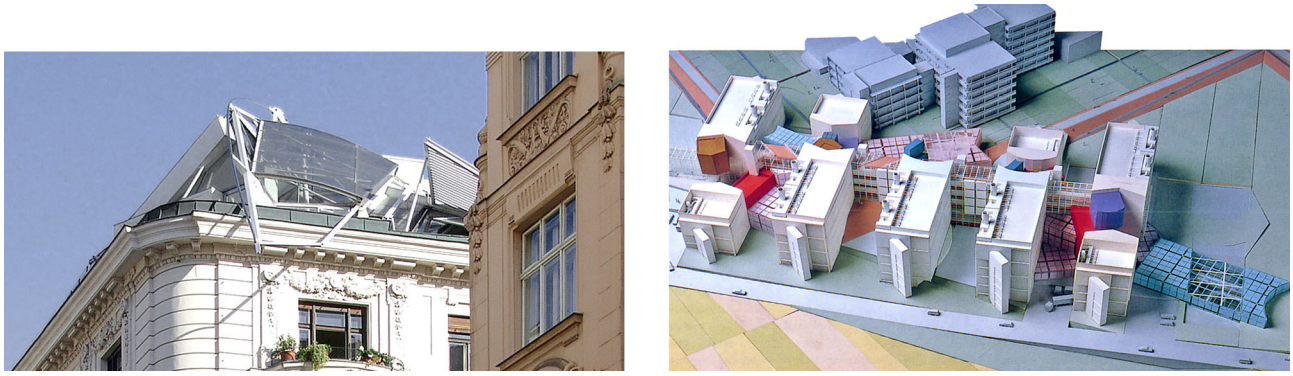

Figure 6: Decomposition method in architecture: left: rooftop remodeling above Falkestrasse in Vienna (by Coop Himmelb(l)au, 1983), right: project development of the University in Frankfurt am Main (by P. Eisenman, 1987)

Figure 7: Guggenheim Museum in Bilbao (by F. Gehry, 1997) in comparison to computer simulations made by author – as an example of deformation of architectural form

Figure 8: Computer modeling of blob forms – example of deformation. Left: simulation with use of Bryce 5.5 program; right: Kunsthaus in Gratz (by P. Cook, C. Fournier, 2003)

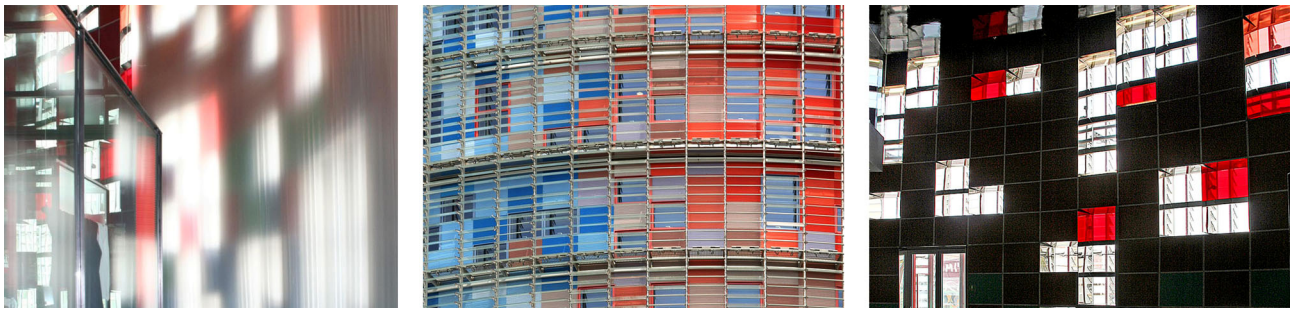

Figure 9: Application of dispersal in the composition of the facade of office building – Torre Agbar in Barcelona (by J. Nouvel, 2006)

2003. The composition of all facades is determined by 'pinwheel tiling', an non-periodic tiling developed and described several years earlier by American mathematician Charles Radin [13]. A simple and repeatable construction produces a complex result (fig. 10). Although the complex is a rather direct quotation from mathematics, the mechanism of developing its form can be planned. The rule of 'pinwheel tiling' can be described using the IFS method [15, 11]. Minor modifications of the rule comprise a specific encyclopaedia of complex forms, and intuitive predicting of the result extends beyond human imagination (fig. 10). Another later example of a facility is the centre of water sports in Beijing developed for the Olympic Games of 2008 (by PTW Architects), where the geometrical form results from using the Weaire-Phelan model.

4. CITY COMPLEXITY AND URBAN PLANNING

Methods of complex form classification presented in the article can also be used in urban planning as tools for interpreting the development of a city and its structures. However, it is not possible to extrapolate architectural observations directly on urban planning. It results from basic differences between the notion of architectural and urban creation. The goal of architecture is to develop building facilities from scratch. The immediate spatial context, neighbourhood of other buildings, can be important for design decisions. However, by nature, creating architectural facilities is a one off activity enclosed in time (from design to building). Obviously, the process of city development is much more complicated and has a different nature. Usually, a city already exists at the moment of 'urban intervention'. It is developed continuously. Thus, complexity is not a predetermined goal but a starting point for designing. For these reasons, contrary to architectural creation, an analytical process is a basis for urban planning.

4.1 Application of the complexity classification in urban planning

Methods for developing complex forms: deconstruction, deformation, dispersion and new complexity have been formulated to support methodical division and creation of architectural forms. In urban planning, the method gain their new meaning and other applications.

The decomposition method in architecture is closely linked with ideas of deconstruction, and can be a tool for various geometrical experiments and computer simulations, which may inspire the process of architectural design. In the urban scale, an equivalent of applying the method is imposing a new structure in a city, such as rebuilding of Paris in the 19th c. according to plans by Georges Eugene Haussmann. The decomposition method can be a mere tool for a methodical organization of such spatial transformations of a city. The potential of the method in creating new geometrical simulations in urban planning is doubtful (may lead to controversies).

The deformation method in architecture is mainly expressed by effort of creating fluid, liquid forms and using complex ruled or non-ruled structures. However, both presuppositions of the method and origin of architectural folding are much broader. The first pioneering examples of the trend is an urban project of the Rebstockpark Housing Estate in Frankfurt on Main by Peter Eisenman (1990) [15]. The urban parametric modeling (UPM) [18, 10] fits into the formula of the method, which proves the possibility of recording and transforming the structure of the city as a set of combined elements from the scale of projection to façade detail.

The dispersion method in architecture, which introduces a random factor to the composition, has the strongest influence on the facade or outer surface of a building. The significance of stochasticity in urban planning is much broader, naturally embedded into the process of planning and the structure of the city. Master plans usually define objectives at a general level while reserving space for individual

architectural solutions (e.g. color, composition of facade, roofing, variable height of a building within permissible scope, etc.). Possible applications of the dispersion method in urban planning are much broader than in architecture. New tools can be used for e.g. analyzing plans and examining the morphology of urban structure.

New complexity, as a method of creating or interpreting forms, is more developed in urban planning than in architecture. It is sufficient to refer to research by Michael Batty presented in the several publications and books: 'Fractal Cities' (1994) [2] and 'Cities and Complexity' (2007) [1]. Using emergence in urban planning is expressed in methods of simulating urban growth using cellular automata (CA) or simulations supported by the agent based modeling. The scope of searching for the system of higher order focuses on the area of analysis rather than creating new spatial solutions. However, nowadays the potential resulting from advanced urban analyses is crucial for the direction of city development.

4.2 The nature of the city complexity

What is the source of complexity in contemporary cities? Is it the result of stochastic activities or phenomena (related to dispersion method)? It the organization based on mechanisms described in the article as a part of the new complexity method? Trying to find answers to those questions is inspiring in itself. Although one cannot expect equivocal results, each examining the boundaries between various categories of complexity of the urban tissue broadens our knowledge about the structure of a city and enhances our designing capacity. This issue has been a subject of various research [1, 12]. A fractal organization can be found in some simple urban systems. The language of the new complexity method can be used to describe an African village of Ba-ila [4], or plans of renaissance ideal cities. Figure 11 below presents examples of computer simulations developed using IFS and cellular automata CA.

The degree of complexity of contemporary cities is much larger and even if we find specific mechanisms of mathematical self-organization, undoubtedly the stochastic factor is an important component of their structure. Figure 12 includes an example of using the dispersion method while analyzing a part of Berlin, Germany. Consecutive stages of the simulation use simple transformation of the city structure (shifting, rotating). Slight 'movement' of buildings in Berlin changes completely its urban tissue. Differences in urban systems blur at various stages of the simulation, which can define the degree of the primary organization. An attempt to interpret complexity was made by the author in his exhibition of 'Images of Complexity' [14] which artistic aim was to look for relations between the structure of a city and dispersion and new complexity (fig. 13).

A visual complexity of a city provides a separate plane for interpreting. Urban structure reflected in a projection is a mere simplification. In fact, a man perceives a city as a set of thousands of various views, combined into a certain whole in minds of inhabitants [9]. Tall buildings have particular significance for developing of the 'image of a city', which range of visual impact is in principle larger [3, 20]. The development of simulation techniques creates possibility of precise analysis which is a subject of research under the 2TaLL Project. Further research should focus among others on defining comparative relations between visual complexity and complexity of the city geometrical structure.

5. CONCLUSIONS

Tendency of shift from classic understanding of systematics towards creation of complex forms in contemporary architecture is clearly seen. It is influenced by new techniques of computer modeling and digital CNC prefabrication. In recent years we can also observe indisputable progress in sphere of modeling and

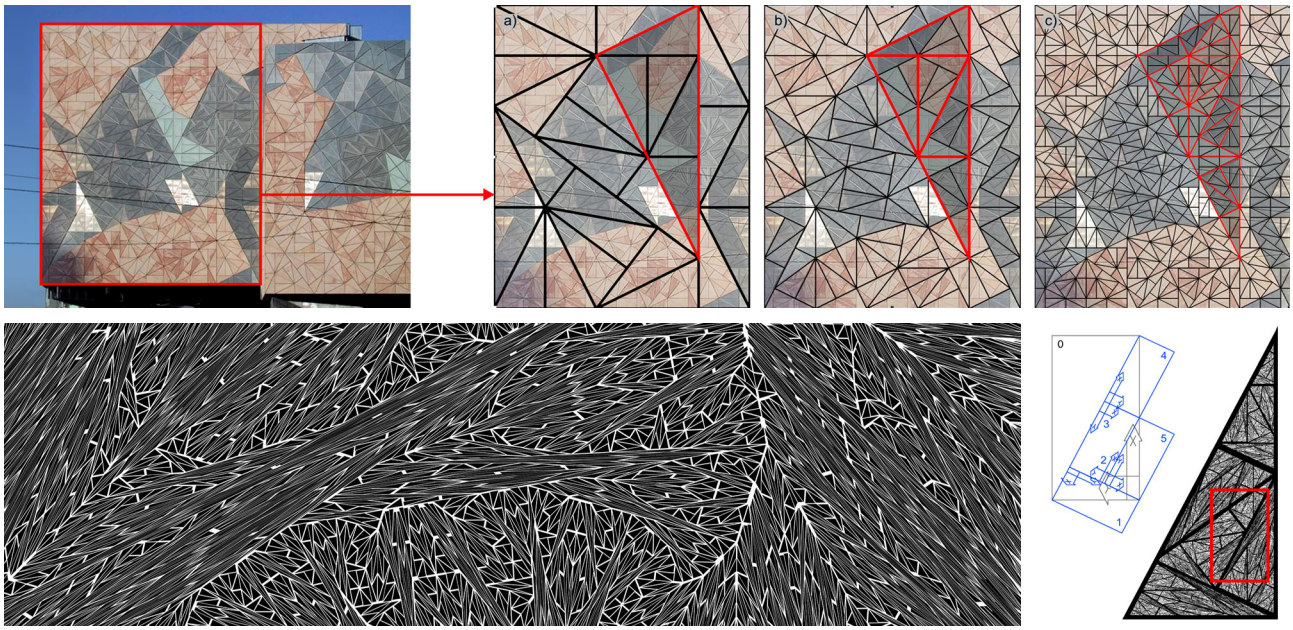

Figure 10:Composition of the facade of Federation Square in Melbourne (by Lab A-S) – example of application of new complexity in architecture. Original view of façade (above) and example of radical reorganization of composition by micro modification of its construction scheme

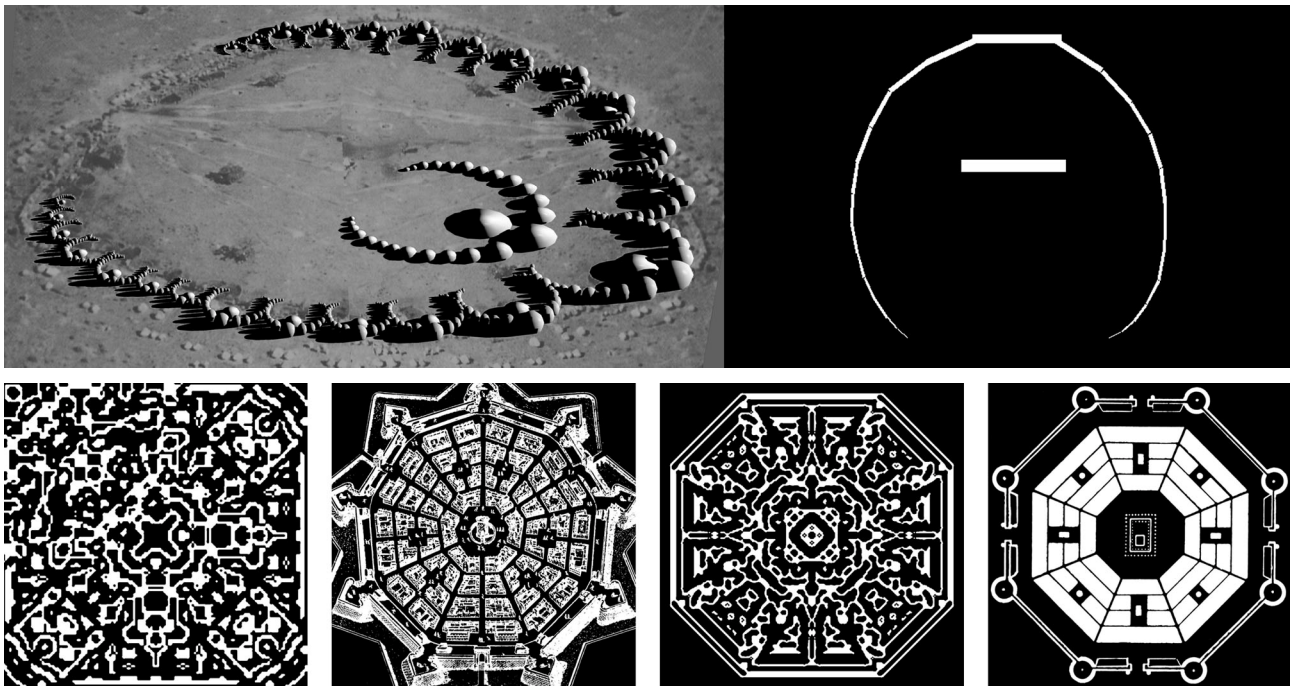

Figure 11: Sample computer simulations prepared with application of IFS method and cellular automata (CA) method. Above: African village of Ba-ila, below: plans of Renaissance ideal cities compared to simulations of cellular automata (CA)

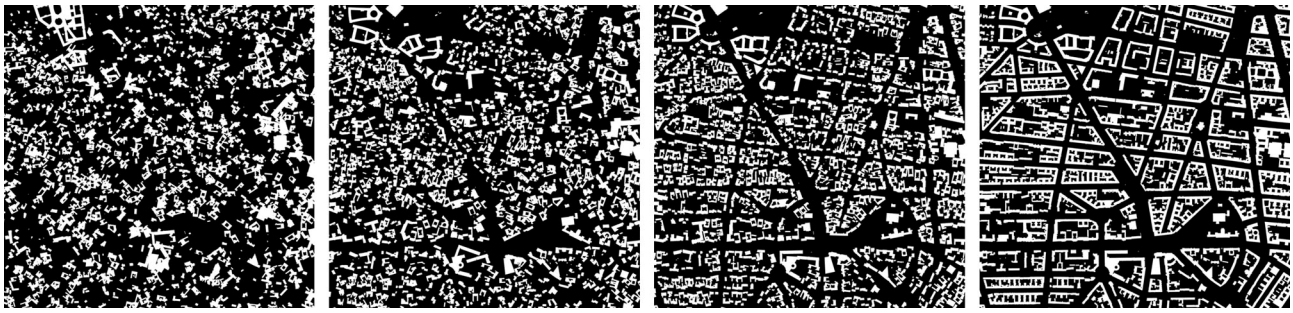

Figure 12: Dispersion method used in analyzing a part of Berlin, Germany

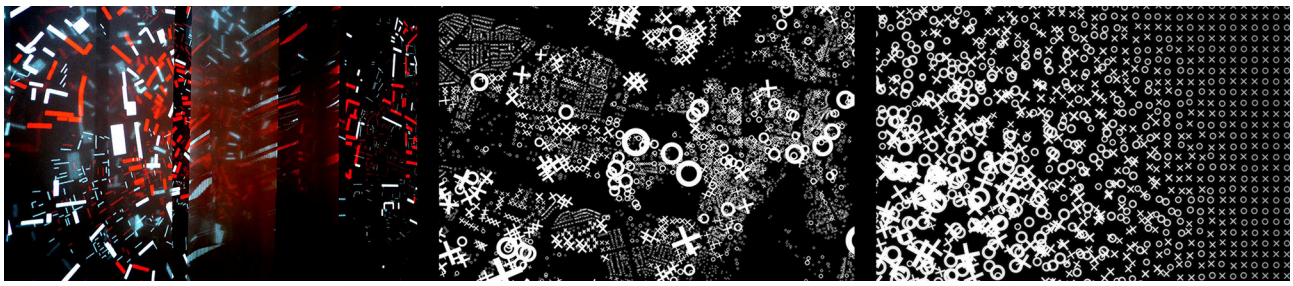

Figure 13: Interpretation of city complexity as a part of authors exhibition 'Images of Complexity' (Toruń 2014)

visualizations of cities. Quantity and accuracy of accessible 3D virtual city models increases rapidly. However, in architectural design the purpose is creation of new forms (buildings), so in urban planning the key importance is process of analysis of city. 3D city models allow application of advanced computer simulations for exploring complex urban structures. Both in architecture and urban planning, important subject of creation or subject of analysis is complexity. Geometry becomes universal language necessary for creation of bases for new digital techniques and also for better interpretation of structure of complex forms. The article presents proposal for systematics of complex forms within the four methods: decomposition, deformation, dispersion and new complexity. General examples of application of each method in architecture and urban planning are presented as well. The proposed methods allow better understanding of construction of complex forms. They can be applied as both, interpretation tool for architectural developments, or urban structures. Each or the methods can be a basis for development of specific computer simulations possible to encode in geometry. Therefore, the presented methods can be a design tool as well.

ACKNOWLEDGMENTS

This research was funded by a Norwegian Financing Mechanism. Digital model of Berlin provided by Berlin Partner GmbH. All other 3D city models used for simulation were made by Cyber Urban Center at WPUT Szczecin. I gratefully acknowledge this support.

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