Complexity in construction

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Abstract

In comparison with nano technology and life sciences, architecture, urban planning and construction related engineering seem to be very simple scientific subjects: Reality proofs that anyone is able to realize a building or to develop a formal or informal urban quarter, but only few are qualified to crack the DNA code. But time has changed: The broad discussion about sustainable development during the last two decades has brought back to construction an almost forgotten dimension: complexity. This paper deals with the potentials, opportunities and risks emerging from a practice-oriented dialogue about complexity and its re-establishment in architecture and urban planning.

1 Introduction

Talking about complexity means talking about complex systems and complex processes. Before entering the challenging discussion about complexity the terms *system* and *process* should be outlined briefly.

A system is an entity that consists of various elements that are linked and that interact. The characteristics and the behavior of systems are primarily determined by the interaction among the elements and the interaction between the system and its environment. This is best illustrated by a well known saying of Aristotle: “An entity is much more than the sum of its elements”. Such interactions could be of a physical (goods, energy, etc.) or an abstract (information, feelings, etc) nature. Checkland[1] distinguishes four categories of systems:

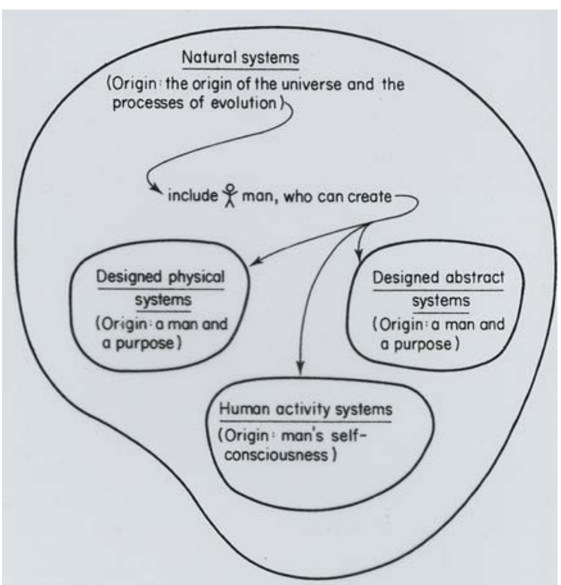

Figure 1: Categories of systems according to Peter Checkland[1]

A process consists of a series of activities and decisions. It has a clearly defined starting point and a clearly defined end. The activities are logically structured, either in sequence or in parallel and they might include feed-back and feed-forward loops. A process has a well defined input (raw material, basic data, etc.) and an expected output (finished product, information, etc.). Usually processes are described in the format of flow charts.

2 Complex systems

According to Mainzer[2] a complex system consists of many highly interrelated elements and it is dynamic, dissipative, non linear and self-organizing.

Dynamic means the system changes its status, characteristics and behavior over time. Such changes might take place within a fraction of a second or over a longer period which could be considered as short in comparison with the whole life cycle of a system.

A dissipative system is an open system that maintains an intensive flux of energy and materials (metabolism) with its environment. The opposite is a trivial system, e.g. a gas in a completely closed container that – according to the 2nd Main Law of Thermodynamics – strives for a status of maximum entropy, which means a totally regular distribution of the gas molecules.

Linear mathematical equations are easy to solve and lead to one well defined solution, whereas nonlinear equations in general cannot be solved clearly and usually have more than one result. Nonlinear systems are unstable and difficult to predict. Their behavior is strongly influenced by their starting conditions and the relevant boundary conditions. They show points of instability (bifurcation points) where new and unexpected solutions may emerge. Depending on the starting and boundary conditions, non linear systems may develop chaotic trajectories which in the long term are not predictable. Managing nonlinearity means looking for, and keeping, a dynamic balance close to a point of instability of a system without falling into chaos.

Non linear dynamics does not lead only to chaos, but also enables self-organization of order (structural and behavioral rules and patterns) in complex systems. Such order emerges from feedbacks between the elements of the system by which effects of causes become causes themselves. This leads to macroscopic structures which are not predefined by the microscopic characteristics of the elements of a system, but created by their interdependence under the assumption of favorable starting and boundary conditions.

To illustrate the rather theoretical and abstract derivation some examples of complex systems shall be mentioned: ecosystem, human society, human brain and urban habitat.

3 Complex processes

Analogous to the above mentioned definition of complex systems, a process is complex, when the objectives of the process are fuzzy and unstable, the boundary conditions are in constant change, basic information is incomplete and uncertain, the outcome is not well specified and the structure of the process is non linear and includes a lot of interlinked loops.

In contrast to an ideal process according to the common theory of process engineering and process management, complex processes are characterized by incomplete, fuzzy and changing goals that finally become completed and bindingly specified during the process itself. Processes with long process durations are particularly influenced by changing legal, technical and financial boundary conditions. Another dominant characteristic of complex processes is the incompleteness and uncertainty of the relevant basic information. Many process activities and decisions are based upon random data, assumptions and estimations. This lack of reliability directly increases the risks (threats and opportunities) and these uncertainties compound to influence the anticipated outcome of a complex process. It is evident that the scope of the end product has to be adopted and optimized due to these constantly changing constraints and targets. Thus, the process itself cannot follow the theoretical logic of an ideal procedure: activities have to be repeated and decisions have to be taken into account again, which leads to a nonlinear sequence of the process steps with many interrelated feed-back and feed-forward loops.

Again, some examples shall illustrate the peculiarities of complex processes: biological evolution, parenting, basic research and designing a building.

4 Complexity of the built environment

4.1 A glance back

If one tries to apply the above definitions of complexity to the built environment and its development it seems obvious at first glance that neither buildings nor the design and construction process show any characteristics of complexity. To the contrary; architects and engineers try hard to waive away all elements of complexity in order to achieve on the one hand a strictly linear, analytical and rational process of design and construction and on the other hand a safe, durable, functional and efficient building forever.

Architects and engineers generally eschew uncertainty and unpredictability. They are trained to develop their works in perfect accordance with well defined architectural theories, design concepts and even aesthetic rules. However, some architects and engineers claim to be the masters of complexity. In reality they are often the victims of the complicated system which they have to develop. To overcome this dilemma they try to abstract and simplify. But the dogmas of abstraction and simplification are the enemies of complexity.

The fight against complexity, this means the triumphal march of abstraction and simplification in architecture and urban planning, has not only brought to us the monocultural cities with their boring, if not to say pathogenic, segregation of living, working, service, cultural and leisure areas, but also the cancer like sprawl of equal housing units and uniform office buildings that one can directly attribute to a certain decade and therefore to a specific architectural stream or school. In addition, laws, regulations, standardization and globalization have strongly supported this trend toward a globally unified and regulated appearance of our built environment.

Already more than 50 years ago some sensitive architects have raised their warning fingers. In 1950 Robert Venturi developed in his thesis[3] at Princeton University his plea for a narrative architecture of vividness and symbolicity which respects the context in such a way that existing conditions and elements around a site should become a part of the design problem. He fought against abstraction, simplification and the dominance of standards, types and norms in Modernism, i.e. he appealed for the re-establishment of complexity in architecture. This thought of inter-relatedness between a building and its social and natural environment was deepened by Venturi in collaboration with Denise Scott Brown[4] since the 1970s, leading to the idea that buildings should not only integrate with their context in a static way but may actively contribute to the changing and pulsating patterns of the associated human and natural environment in the sense of an ongoing and dynamic dialogue – thereby providing a quantum improvement to the site's context through the building. According to my perception these ideas marked the hour of birth of complexity in architecture and urban planning.

I am convinced that 50 years later, the time has come to re-think the meaning and the role of complexity in construction. Complexity in construction has a lot in common with sustainable development and in particular with sustainable construction. Hence it is an issue of high relevance which asks for critical arguments amongst the most renowned professionals. Being well aware that I am neither an architect nor a philosopher, I would like to initiate herewith a broad discussion about this topic and the Holcim Forum 2010 could provide the starting platform.

4.2 Complexity at the building scale

In order to discuss complexity at the scale of a single building I like to refer to the general definition of a complex system which we characterized as a dynamic, dissipative, nonlinear and self-organizing entity containing many interrelated elements. From a broader perspective, it is evident that buildings as physical, human-made systems might be more or less complex. If one applies the criteria of sustainable construction (e.g. as defined by the five "target issues" of the Holcim Foundation for Sustainable Construction) there is no doubt that a building has to be complex in the sense outlined above. But what does this mean in reality?

A building is composed of many closely interrelated subsystems and elements. The dynamics of a building relate to its adaptability to any kind of change such as alterations in use, operation and ownership, alternative ways of financing, new laws and regulations as well as future materials and technologies. The request for metabolism (dissipative system) addresses not only the exchange of energy and materials between a building and its environment (air, water and soil consumption and pollution, public utilities etc.) but also the social and aesthetic integration of a building within its neighborhood, the connectivity with regard to mobility (individual and public) and services (schools, shopping facilities, hospitals etc.) as well as the accessibility for the public. Nonlinearity refers to multiplicity and multipurpose functionality. First example: a building envelope shall not only protect from rain, humidity, temperature, and summer sun penetration – but also allow views to the outside, provide daylight, collect rainwater and produce energy. Second and third example: a housing unit shall be adjustable to the needs of the different life sequences of a family (no kids, with children, with adolescents, and then towards "empty nest") or a habitat should enable cohabitation of people from different nationalities, cultures and religions. Self-organization means on the one hand buildings designed for and managed by the users e.g. user participation at all stages of the building's life cycle and on the other hand buildings being able to keep this flowing balance between constant change and conservation.

As already mentioned a building might be more or less complex and the complexity of a building has different facets and backgrounds. The aim cannot be to achieve a maximum degree of complexity but the kind and amount of complexity that is appropriate to a specific situation. The following examples shall serve as illustration of the complexity of a building.

Good practice:
"Green, social and complex" was the vision of Danny Pearl and Mark Poddubiuk, the architects who were the driving forces behind the renovation of three 60-year-old brick buildings on the edge of the inner city of Montreal, Canada, containing a total of 187 residential units. The former owner planned the complete demolition of the old urban fabric called Benny Farm and its replacement. When the first bulldozers arrived on the site, protesters stood up and claimed an alternate solution that keeps and develops the existing structures. The result was a refurbished, low-cost and high-quality residential space with a green infrastructure. At the same time new social and innovative financial concepts were developed. Each building and the shared infrastructure are managed by a specific non-profit organization assuring affordable costs and resident participation.

Figure 2: Benny Farm in Montreal

Problematic practice:
Gated communities are a typical example of a trivial, non dissipative and static system. They are designed, built and operated in order to minimize and control all interactions with the urban environment. Even inside the gated community the single buildings follow rigid patterns reducing change to a minimum and in any case avoiding chaos. Usually also the social structure of the inhabitants is uniform (same color, similar income, related professions and jobs) and not subject to any change.

4.3 Complexity at the urban scale

After looking at the complexity of a single building or a street block it might be interesting and worthwhile to have a look at complexity at an urban scale.

Whereas many of the statements related to a single building are also applicable to a city or a district, some of them need to be adjusted. Urban metabolism, nonlinearity and self-organization have a much broader meaning at an urban scale. If one looks at a city as a complex system the flux of energy and materials between the built environment and the natural environment has a fundamentally different dimension as if one looks only at a single building. Urban metabolism and economy of means are the most crucial issues with regard to urban development. Hence these issues belong to the most intensively researched topics in this field.

Also nonlinearity is more important at the urban scale. As mentioned before, nonlinearity has to do with system dynamics and non predictable development trajectories. Urban systems are much more dynamic than single buildings, especially if one looks not only at houses and infrastructure but encompasses also the social and cultural aspects of a city. By so doing, it is evident that a city or a district may change its structure, characteristics and behavior within a relatively short time period. Many examples around the world illustrate such fundamental social and cultural changes leading also to substantial alterations of the built environment. These developments are usually neither planned nor predictable with regard to their outcome. They emerge near bifurcation points (points of instability) of the urban development and contain the risk of chaos. Managing nonlinearity at the urban scale means fostering change in any respect, i.e. enabling urban development nearby points of instability, without endangering the dynamic balance between progress and conservation or even losing the city in chaos.

At the urban scale also self-organization is of more importance than at the level of a single building. Usually the relation between a building and its users is well regulated, i.e. they are either owners, tenants or visitors, whereas city inhabitants take possession of, or even conquer, and then may later on abandon their district. In the beginning we pointed out that non linear dynamics might not only lead to chaos but also contain the potential of self-organized order. Such order (structural and behavioral patterns) emerges from feedbacks between the elements of the system (in the case of a city the individuals and the social groups). In complex systems these feedbacks lead to macroscopic structures which are not predefined by the microscopic characteristics of the elements, but created by their interdependence under the assumption of favorable starting and boundary conditions. With regard to cities this means that politicians and urban planners ought to create favorable starting and boundary conditions that foster networking and interaction between individuals and social groups. Many of the traditional and well known elements of urban planning contain this potential, e.g. pedestrian zones, public parks, playgrounds, interactive facilities for adults, coffee shops, bars and restaurants, cinemas and theaters, lively market places and small shopping halls etc. Such amenities cannot be realized through private investments alone, they must be initiated and supported, if not to say imposed, by the public authorities. Even in well developed and wealthy cities such as Zurich, a scientific survey has shown that there is a strong need for such initiatives[5].

Good practice:
The river mediation and development scheme in the medina of Fez, Morocco, is a unique showpiece of a joint private/public initiative aiming at the re-development of an abused and perishing historical city center. The decline of the river Fez, once the lifeblood of the ancient city centre, is symbolic of the decay of the medina as a whole. In desperation the local inhabitants started to cover their river with concrete slabs in order to "improve" their unbearable living conditions. Challenged by the threatened loss of the UNESCO World Heritage status, the government has immediately responded with the construction of two water treatment plants and is addressing the re-opening of the river Fez. Two young and ambitious architects, Aziza Chaouni from Fez and Takako Tajima from Tokyo, are in charge of putting this comprehensive rehabilitation plan into

action. However they do not just realize the governmental ideas but they try to revitalize the social fabric and to re-settle historic handicraft and trade back into the medina. In other words, they re-establish complexity in the medina of Fez.

Figure 3: The medina of Fez and River Fez in transformation

Problematic practice:
Mass housing projects are booming in any expanding urban area. One can find them anywhere, from Shanghai to Paris and also here in Mexico City. Usually they are conjured up either by private developers or under government housing programs, forming completely new districts far away from traditional centers. Mostly they are characterized by poor architectural quality, uniformity, low costs and bad quality standards. They are designed and built to fulfill short term goals, either short term financial benefits or short term satisfaction of spatial needs. The users are neither involved in the development of the overall scheme nor in the design of the individual layouts of the flats. Preferably the flats get sold, so that the responsibility for operation and maintenance can be moved from the prime investor onto the shoulders of the flat owners or of an unidentifiable entity. Deterioration of the built environment and segregation of the population will be the predictable outcome. One can say that this is the ultimate stage of complexity, i.e. chaos. But chaos isn't the goal of introducing and managing complexity in construction, it's the dynamic balance between conservation and change that produces new, sustainable solutions.

4.4 Design and construction – a complex process

Every project manager's dream is a project kickoff with a complete set of clearly defined goals and constraints at hand that remain constant throughout the duration of the project, a comprehensive and final scope of the project outcome and a client who takes reliable decisions in time. Everyone who was ever in charge of the design and/or execution of a building or a civil engineering structure is well aware that this is an illusion. However project managers still try to apply the traditional methods and tools of "hard" project management that were developed for such "ideal projects" neglecting the complexity of the design and construction process.

Architects and engineers know very well that a building must be designed and optimized in close collaboration with the owner, the user and the operator as well as in line with the diverse expectations of many external stakeholders such as public authorities, politicians, NGOs and neighbors. Even when targets are precisely defined and properly prioritized, the design process will never be a linear sequence of tasks to be performed one after the other and driven by efficiency, but will always include various feedback loops and bifurcation points revealing new options and asking for reconsideration and compromise. Because the design and construction process usually lasts several years, the likelihood of changing requirements and framework conditions is extremely high. In addition design assumptions might later on prove to be wrong or too optimistic. All these effects dramatically increase the risks with regard to time, costs and benefits. As a result the scope of a building project is clear at the day of its inauguration.

Putting all these characteristics together it becomes obvious that design and construction is a complex process which needs a new kind of project management. Some scientists and practitioners even claim a paradigm shift from the “hard” project management towards the “soft” management of projects where leadership and teamwork are the key success factors while struggling with process complexity. In other words successful processes presuppose a delicate balance between interaction and control[6]. Interaction between those directly involved, but also interaction with external stakeholders through close collaboration based on professionalism, reliability and trust. Control is still a must, not in the sense of looking back as practiced by bookkeepers but forward-oriented and driven by a risk management that masters threats and makes use of opportunities.

5 Playing with complexity

In the beginning I stated that many architects and engineers dislike uncertainty and unpredictability. As a consequence they usually deal reluctantly with complexity. But from my point of view complexity isn’t a threat but in contrast offers a broad range of opportunities. My personal advice is: let’s play with complexity in order to contribute to sustainable development.

But what does playing with complexity mean? First of all it means learning from nature because our ecosystem is a perfect example of a complex system. Nature teaches us openness, nonlinear dynamics and self organization. In the same manner we should accept, design and use single buildings as well as urban districts or whole cities as complex systems, that are highly interrelated with their social and natural environment, that show nonlinear dynamics in the sense that they are uncertain, unpredictable and unstable and contain the potential for self organization nearby bifurcation points where new solutions emerge. Furthermore we should accept that planning, designing and executing a building are complex processes that do not follow strict rules and sequential procedures. On the contrary, the processes are characterized by unexpected zigzags and many feed-back and feed-forward loops. “Playing with complexity” means playing with uncertainty, ambiguity, and instability – with regard to both process and product.

Non linear dynamic systems have a lot in common with ambiguity! With regard to the built environment this means that for a specific problem or request there is always more than one feasible solution and also that functionality must be diverse. A functionality of manifold variety relates to the different components of a building but also to its layout and use. Two examples shall illustrate this: A building envelope should be like human skin. It is multifunctional in the sense that the skin contributes to a large extent to aesthetics; it also protects from dust, water and humidity; and it also breathes and controls the body temperature through evaporation. What a smart and high-tech component without which a human being could not survive! Despite our academic talks about intelligent buildings we are still far away from what nature was able to create through evolution.

The second example deals with the non linear dynamics of space and form. Usually architects design buildings all along the visions and requirements of the client taking into account the peculiarities of the specific site and its environment and following the prevailing laws and building regulations. If one looks at the same building twenty years later it can be recognized that mostly the owner, the use and the users as well as the inner layout and the external appearance have changed. The building has undergone a substantial transformation that was neither predicted nor technically foreseen. In some cases this transformation can be realized easily and in others it needs a tremendous effort and a lot of money. Similar effects can be observed at the urban scale when looking at brown fields or districts in motion.

Playing with complexity means saying good-bye to simplification and abstraction. The built environment as part of our social and natural environment is far too complex for any simplified approaches and solutions. Architects and urban planners have to take into account the complexity of the issues and objects they are working on. They ought to make use in a proactive way of the openness, the nonlinearity and the self-organization of the buildings and districts they are shaping. By so doing, complexity will no longer be a threat but a huge source of manifold opportunities.

Against this background I would like to stipulate some maxims regarding the fruitful management of complexity in construction. Concerning the end product of architectural design and urban planning, i.e. the buildings and cities, we should:

- Consider a building as a strongly interrelated element of a preceding, extremely complex, human and natural system!
- Plan and design not only for the initially defined use but also for unexpected transformations!
- Foster diversity of use, layout, materials and technologies!
- Apply the principle of integration instead of deconstruction and segregation!
- Achieve economy of means and reduce metabolism by multiplicity and multifunctionality (i.e. one item fulfills more than one purpose)!

If we consider the process of planning, designing and executing a building we should be prepared to:

- Take decisions on the basis of fuzzy, i.e. incomplete and uncertain information!
- Involve internal and external stakeholders at an early stage!
- Manage projects through leadership, team work and forward coupling!

These maxims are just hypothetical; they still need to be proven. But if we are not courageous to start on the basis of some hypotheses, we will never find the truth.

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