# PROCESS-DRIVEN ARCHITECTURE

*Design techniques and methods*

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**Abstract.** This paper explores the notion of process-driven architecture and, as a consequence, application of complex systems in the newly defined area of digital process-driven architectural design in order to formulate a suitable design method. Protospace software environment and SwarmCAD software application are introduced and physical, real scale prototypes of architectural installations illustrate the new approach to creating architecture.

## 1. Process-driven Architecture

> proc•ess [ pró sèss, prṓ sèss ] noun (plural proc•ess•es)
> 1. series of actions: a series of actions directed toward a specific aim
> 2. series of natural occurrences: a series of natural occurrences that produce change or development
>
> (encarta.msn.com, 2007)

Computers and digital technologies are truly revolutionizing our lives. It is needles to say how our everyday existence has been changed by all kinds of IT gadgets, from mobile phones and internet to electronic systems in cars and TV's. However, what's equally important is the new way of thinking and working that computers and IT have evoked on us. Since most complex calculations can now be performed within a fraction of a second, we need to focus our creative thinking on ways in which information should be structured, connected and used. In all fields of science we are becoming designers of data processing systems. For that we need to alter traditional disciplines and architecture among them, in order to accommodate this new way of thinking and working.

Traditionally, architecture is perceived as being completely static. We think of it as of physical constructs consisting of interweaving forms and spaces that can be seen, touched and used. However, behind those easy to perceive spatial objects, there are often exceptionally sophisticated reasoning processes which led to their eventual shape. Diverse factors, ranging from functional and safety restrictions through material properties to aesthetical preferences and historical, social or cultural aspects affect the way in which buildings are normally being created. In this way we can say that architecture is a process, affected by all these factors and of which spatial constructs are forms of an outcome.

This outcome, however, should by no means be regarded as definite or final. The process of architecture does not end in the moment of building construction. Our perception may be hindered by often slow timescale in which architecture may operate, but buildings do continuously change after being built. To give an illustration, we may look at Egyptian pyramids that have lasted almost intact for thousands of years. Naturally, we regard them as being absolutely static, or even eternal. Nevertheless, those ancient pyramids had been built gradually. After their building progression was complete, changes were still inflicted on them; directly or indirectly. They have been plundered many times and over centuries they keep deteriorating. Also their setting and context have changed enormously.

*Figure 1.* Materialized architectural processes of different speeds and intensities

Pyramids are of course utmost examples of buildings of seemingly static nature, but even they can be easily regarded as dynamic if space and time of their existence is scaled to more suitably fit with our human perception. However, this dynamic character of architecture becomes much more apparent with buildings more intensely exploited, where users make constant spatial readjustments over time, often as spatially radical, as connecting or separating rooms, constructing additions or tearing down redundant parts of buildings. Those adjustments can also be more subtle, like opening and closing doors or turning lights on and off. All this adds up to the physical phase of ongoing architectural processes, manifested in evolution of buildings over time.

Therefore, in the contemporary age of immediate information, when our living environments are fluctuating more and more rapidly in practically all their aspects, it becomes extensively practical to consider buildings not as static, passive objects, but as beings which keep on changing, in other words - which are continuously “becoming” as in philosopher’s Henri Bergson’s worldview. Seeing architecture from this perspective should encourage us to taking into account that those process-driven entities may need to be instantly connected and potentially respond to all dynamic variations in every factor that has originally contributed to their spatial manifestation.

Such processes of architecture do not have precisely defined start or end points. Even though a building becomes physically built at a certain moment in time, the process which led to that creation can be theoretically traced back endlessly, following each logical thread which might have in some way affected the materialized building form. However, from architect’s practical perspective, it would be useful to start reflecting on that process from the moment when the first virtual idea of designing a particular entity becomes distinct. From that moment on, after being virtually conceived, just like a living creature growing in the womb of its mother, to eventually become a separate organism capable of existing on its own, buildings start to be virtually formed by their designers. After that virtual forming is complete they eventually may “get born”, become materialized, or in other words be built. Yet, that initial design process which formed them up to that stage doesn’t end there. Buildings keep on changing. They keep on mutating and re-adapting, always in constant relation to many elements of their direct and indirect environment and eventually they deteriorate and fall into pieces. Thus, the building may ultimately disappear as a whole, but nevertheless its processes in many ways would still continue, again virtually, leaving both physical and virtual traces behind, in certain ways lasting infinitely.

Consequently, in order to summarize this introduction with a concise definition of the notion of process-driven architecture; *process-driven architecture is a process which becomes materialized in space and in which people can participate*. The participation of people is required in this definition as it differentiates architecture from all other kinds of natural spatial phenomena. Nevertheless, this definition stays very open and it doesn’t in itself imply any specific type of architecture. Rather than that, it stands for a different way of understanding and dealing with architecture than traditionally practiced. Instead of diverging designers to reductionist classifications of building types and their components, it gives priority to seeing buildings as systems of interrelated elements. Such systems form ecologies of relations on very diverse scales. A building itself can be a system of related elements, but each of those elements can include ecologies of its own, as well as whole buildings can be parts of greater ecologies of their environments.

Process-driven approach to architecture can be pursued purely conceptually, but its true potential can only be unleashed with the use of digital techniques. Complex architectural models can be translated to digital systems made up of parameters and relations between them. Even though those could be to a certain extent described non-digitally and analyzed on paper in form of simple semantic networks, it is the digital technology that can allow applying those systems in practice, executing their dependencies and allowing them to perform dynamically.

## 2. Complex systems in design

> Complex Systems are systems that comprise many interacting parts with the ability to generate a new quality of macroscopic collective behavior through self-organization, e.g., the spontaneous formation of temporal, spatial or functional structures. This recognition, that the collective behavior of the whole system cannot be simply inferred from the understanding of the behavior of the individual components, has led to various new concepts and sophisticated tools of complexity.
>
> (Kaneko 2006)

Creating architecture as a process is a difficult task, however attempts in this field gradually spread from avant-garde experiments to more common, universal architectural praxis. Nevertheless, the amount of problems that need to be addressed and solved is overwhelming, since the area of concern covers practically every aspect of architecture, from early design to building construction and building maintenance and performance. In design phase practical attempts usually involve creation of models which consist of a certain number of adjustable parameters and relations between those parameters, with their outcome manifested as a spatial, virtual form. Such parametric models can serve as basis for further production drawings of buildings. In next step; manufacturing of a building, fabrication of components can be fully numerically controlled. The most commonly used abbreviations for this practice are CNC which stands for “computer numerically controlled” or F2F for “file to factory”. Those new technologies have a significant impact on architecture, since their direct consequence is that architects are no longer dependent on mass production of repetitive, identical building elements. Given that machines are digitally informed as of what to produce, if they receive diverse data, they can manufacture large amounts of fully individual elements, without any increase in manufacturing costs. Last but not least, practically every component of a building can now be dynamic. Sophisticated sensors of various kinds can gather different sorts of relevant data directly from building users or indirectly from sources such as internet or other information networks. Large computers or small microcontrollers process this information. Eventually, actuators turn the output of that processing into behavior of buildings. This behavior can be manifested as changing light color and intensity, whole displayed images, played sounds or kinetic motion, which all together can form very powerful interaction.

Availability of all those digital, hence process-driven, techniques and technologies leads to the urgency of finding methods that could facilitate creation of architectural processes that being capable of binding all those elements together within one methodology of architectural creation. However, the amount of data the calculation of which needs to be handled in such design processes is absolutely beyond direct perceptive capabilities of one person or even entire teams of people. Hence, means need to be found that would allow full use of such overwhelming amounts of data in designs and at the same time making it possible to retain needed amount of control over such entire system and the embedded in it, ongoing architectural creation process.

Developments in IT have triggered intensive research and studies of complex systems as new means of understanding and dealing with diverse kinds of problems in science and philosophy. New paths have been opened for making it possible for computation to deal with many, previously unsolvable issues. The book of Stephen Wolfram "New kind of science" (2002) may be criticized by many scientists as in several ways superficial, yet it has been definitely a milestone that brought together under one umbrella different topics that have been widely researched upon in last decades. Next to it "Intensive science and virtual philosophy" (2002) by Manuel De Landa bridges the gap between new emerging sciences and contemporary philosophy and "Architecture goes wild" (2001) of Kas Oosterhuis creates a similar bridge between the new ways of science and architecture. Even though it has so many complicated implications, this revolution of thought can be traced down to one simple idea, the notion of complex systems.

Complex systems are systems consisting of a large number of interconnected, yet autonomous elements. Each of those elements may be behaving in very simple ways, however the system as a whole can exhibit a very sophisticated behavior, often thought of as close to intelligence. Examples of such systems range from insect colonies through tornados to human brains. Each of those systems is driven by uncomplicated behavior of its basic, simple components, such as ants, atomic particles or neural cells; yet the system as a whole shows very complicated and often unpredictable performance. Author's hypothesis states that such systems can be used as basis for formulating a new methodology for creation of architectural processes as well as combining into one system various new techniques currently emerging on the border of architecture and information technology.

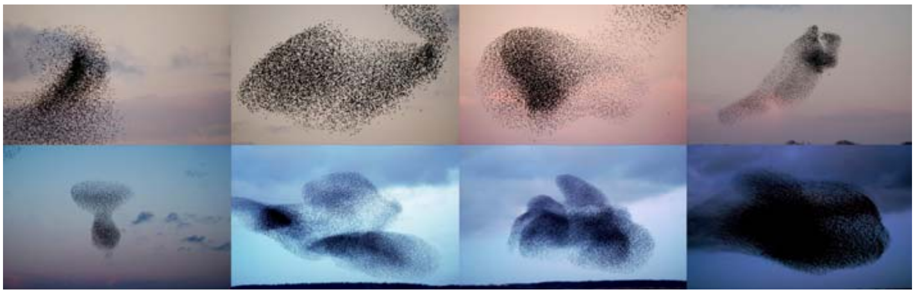

*Figure 2.* Swarms of insects forming a complex system of collective intelligence

In creating a complex system, a lot can be learned from nature. In fact, every living being, seen as composed of countless smaller components, could be considered to be such a system. If we trace processes that form living organisms, it's obvious that none of them had initially been shaped in all its intricacy. They always start with a single cell which multiplies itself many times. When a critical mass is reached, cells start to differentiate, they begin to form tissues and organs. Along this process, relations between cells emerge and an appearing organism can start to receive impulses from its environment. At first it is highly dependent on its protective surrounding such as an egg or mother's womb, but eventually it gets born and starts to relate itself to its real living environment. It keeps on learning, growing and adapting throughout its entire existence.

Analogically, buildings are at first virtually formed by their designers in the beginning of design processes. They gradually become more and more detailed and eventually can be materialized, or in other words built. However, that process which formed them up to that stage doesn't end there. Even though an architect may not be involved in it anymore, buildings keep on mutating and re-adapting to their environments; they grow mature, and eventually deteriorate, get old and die. Consequently, if we would approach this process in the same way nature did, we could gradually control, with full awareness of its intricacy, the entire formation and complexification of buildings, without a need to directly handle and define every parameter and every relation that has to be formed. In this way we could allow certain features of buildings to naturally emerge from the system, yet without loosing precise control over how an architectural being is created. This process can somewhat be comparable to natural breeding and growing of plants as contrasted to trying to assemble a plant molecule after molecule. However, the main difference with biology is that architectural processes would originate entirely in the virtual, digital setting. Yet, even so, after building's materialization, elements of that virtual system could keep on operating within the building itself and as parts of its environment.

*Figure 3.* 751 multiplayer design - a 3d city project - outcome

Despite such explicit analogies, this entire approach may still appear unclear, especially regarding its pragmatic application to architecture. To provide a more vivid example of how complex systems could be easily used, an experimental student project can be used as a case. In 2006 a design course directed by prof. Kas Oosterhuis and co-tutored by the author was held at the Hyperbody, a sub-department of TU Delft's Faculty of Architecture. Twenty three students were asked to design a three-dimensional urban structure filling an imaginary sphere of 200 meters in diameter. Asking students to come up with one design as a group would have probably resulted in a repetitive, uniform structure, not having many properties of real cities, which normally exhibit great diversity and intricacy. Instead, each of the students was provided with a three dimensional zone with a predefined location and borders within the sphere. All students were free to design any architectural spatial form within that zone, as long as the predefined functional program of demands for the entire area was satisfied. In this way students started with individual, local design concepts and their subsequent design process was focused on connecting and adjusting those initial concepts to neighboring projects in various ways. Some projects demanded structural support from others, other ones required traffic connections or transportation of goods through different parts of the 3d city. In this situation every student had to operate like an ant in the hive; to allow the entire system to progress as a whole by locally adjusting its small components. In this example there were only 23 cells, each of them consisting of numerous smaller parts and locally controlled by individual students. At the same time course leaders were having a role of process-architects of the entire city, designing the system and supervising the students, but not having direct control of all their actions.

In the same way as the process for the 3d city was designed, we should be able to create much more complicated systems, composed of self adjusting entities, together forming a network which could be altered and supervised, but still to a high extent stay emergent in its nature.

## 3. Digital design tools

To achieve the complicated task of building process-driven architecture along the complex system agenda, radically new design methods have to be developed. In principle such methods should allow starting design processes with very simple entities such as points or cells without any specific properties nor parameters. Gradually more parameters should be added while cells become differentiated and diverse relations forming ecologies between those cells should appear. Each cell should have autonomy and be able to perform basic logical operations on its own. On the other hand, there should be certain level of control over the whole system, also allowing steps back in the process and exploring different branches of process development. The work of an architect supervising this kind of processes could be somewhat similar to an imaginary scientist, genetically breeding a new sort of biological species and at the same time supervising the growth of one representative of that new kind, while still working and improving its genetic code while it grows. The only difference is that this organism at that stage would be purely virtual and created within a computational environment.

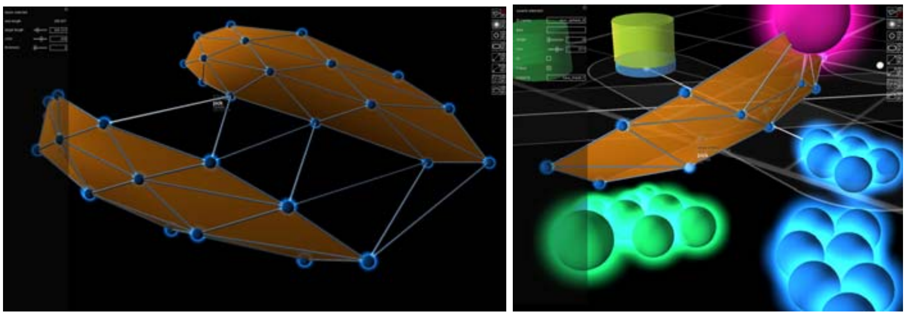

*Figure 4.* SwarmCAD - working application screenshots

For that purpose author's research includes development of a software application capable of handling interactions between autonomous digital objects of different, flexible types. Developed under the working name of SwarmCAD, the program can already deal with a variation of object state-types, thus with elements that can multiply and diversify themselves and in this way form greater systems. The most difficult part of this development is to provide the right amount of control over the system, not to let it fall into chaotic behavior, while on the other hand allowing its spontaneous, emergent performance. Such system may be extremely powerful, yet if not backed by other more specialized tools it could only be used in very early design stages. In order to enhance the system with parameters related to, for example, structural performance, cost analysis or environmental factors, it needs to be linked with other specialized applications capable of more specific calculations. To allow this kind of performance, Hyperbody team, in which the author takes an active part, develops the Protospace.

*Figure 5.* Protospace lab placed in the F2F manufactured iWEB pavilion

Protospace, an initiative of prof. Kas Oosterhuis is being developed as a vehicle for transdisciplinary research, education and design in form of a virtually augmented transaction space. In principle, Protospace allows working on different software platforms simultaneously, allowing real-time collaboration between diverse specialists in the design team. Out of normally distributed design data and its processing, Protospace forms one distributed, real-time network which not only makes the entire design process much more efficient, but it allows for unmatched improvement of reached design quality, allowing designers to freely explore endless design variations.

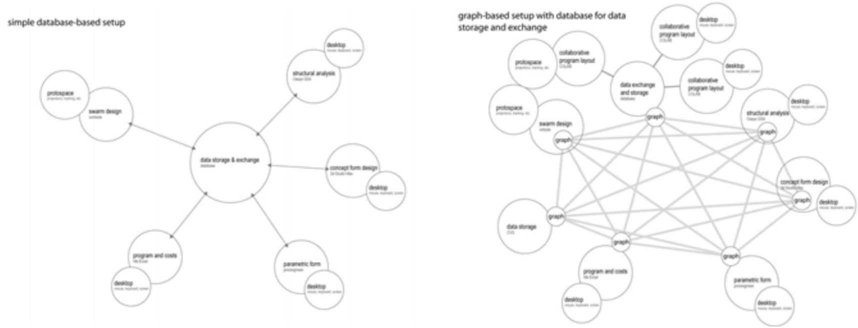


*Figure 6.* Protospace system without and with the XiGraph protocol

The recently introduced core element of the Protospace system is the XiGraph protocol developed by ir. Christian Friedrich. XiGraph is practically a cross-computer semantic network of data cells and relations between them. It allows creating real-time connections between information present within different software applications. This data can be synchronized instantly at application runtime. What's more, different versions of the entire graph can be stored, thus exploring variants and different branches of an ongoing process is possible. In this way one application, in author's case SwarmCAD, can handle the evolution of the architectural process, while other applications and working with them specialists, in parallel to each other, can calculate potential performance of the project and its elements in different areas, such as cost efficiency, structural performance, environmental performance etc. Other software applications can be added to the entire system if needed, for example using such techniques as genetic algorithms, L-systems or advanced generative geometries. Among all those tools, the very important module for architectural design is the 3d geometry modeling program. There are many available solutions; potential options include using conventional 3d modelers such as Autodesk 3d Studio MAX or Autodesk Maya. In those programs it's possible to create scripted geometries responding to varying parameters. However, for the presented method it may be more suitable to use programs such as Bentley's Generative Components (Aish, 2006), which is fully parametric in its core nature and each geometric element created in it becomes automatically turned into a script code and a relational graph representation. Therefore it may be more reasonable to communicate that already formed data structure within Protospace XiGraph rather than recreating custom scripts for every running project. Currently diverse options are being tested.

## 4. Design materialization, design performance

Traditionally, when design of a building is finished, production plans are prepared and the building can be constructed accordingly with those plans. Afterwards, the building starts being used and has to be maintained. However, with the process-driven approach, this division between designing, construction and maintenance becomes very vague. Those three phases don't have to be carried out in a sequence anymore; they can be in many aspects simultaneous or even mixed with each other.

If a design process consists of a high number of autonomous elements and reaches a stage in which some of those elements representing physical components of a building don't evolve anymore, those components can be instantly CNC manufactured. While some parts building parts may still virtually evolve, other parts can be already assembled. In that case the virtual system would be informed that the materialized elements are fixed. It could also receive additional data coming from the building site of how the materialized elements actually perform in the physical space. In this way the design process may keep on running virtually, complimentarily to building materialization. It can even last after all physical components of the building become materialized, serving purely for data processing, feeding information to materialized building elements which can stay open for alteration during the building lifecycle. For this, it would be useful if original virtual data processing objects could be seamlessly extracted from the software and ported into independent microcontrollers. Such devices could keep on functioning as parts of a network, capable of exchanging information, sensing their environment, processing all inputs and manifesting it by sending information back to the network and to directly connected actuators.

This can lead to dynamic building performance and can greatly facilitate further building evolution. In the same way that designs originally would have evolved virtually, materialized buildings could continue that evolution further. Their geometries could either rapidly change in their dimensions with use of kinetic actuators or their topologies could be reassembled by producing new components and replacing old ones. Light and images, sound and other media can be embedded and be part of the entire building system. Fragments of that system can function as a physically formed network; other fragments can operate within server computers or even over greater networks connecting to other similar developments.

To validate the physical part of the presented approach, several concepts have been tested and prototyped on 1:1 scale in numerous case projects. New materials became sensing and actuating organs of buildings and digital information processing worked as their neural system. This allowed to radically enhance adaptive and performative qualities of designed spatial installations.

*Figure 7.* Muscle Space: sensors, actuator and dynamic behavior

The Muscle Space project, one of those installations, was developed under supervision of prof. Kas Oosterhuis by the author, together with ir. Christian Friedrich and a group of BSc6 students of TU Delft Architecture, as part of their study course. In this project a 1:1 scale prototype of an interactive spatial structure was built. A number of pressure and proximity sensors were used to sense motion of people around and within the structure. That stream of data was being processed on a server computer, running a script made using Virtools software development platform, which was sending data further to various actuators. Among them Fluidic Festo Muscles served as kinetic actuators setting the walls of the structure into dynamic motion, speakers were creating a spatial sound feedback and three digital projectors were displaying visual feedback in form of a wave texture on the entire structure.

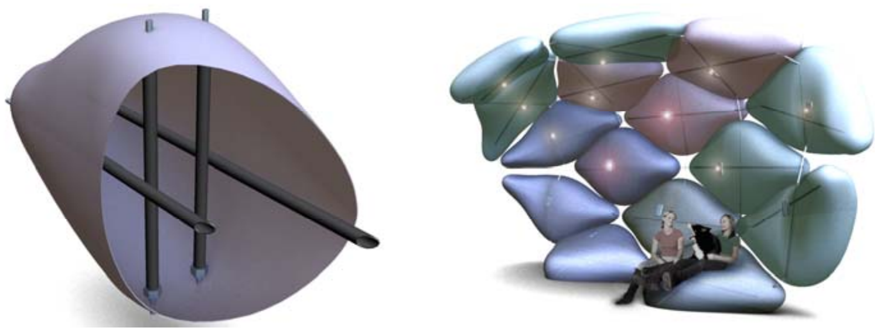

*Figure 8.* Bubble Lounge prototype case study concept

The disadvantage of that system was that the entire data processing had been centralized and would become highly inefficient for larger structures. The next prototype with a working name “Bubble Lounge”, currently in development by the author, consists of an array of inflatable dynamic cushions. Each of the inflatable elements uses a separate standalone Wiring microcontroller for data processing. This data comes from a number of sensors and other cushions. It is processed and sound, light and kinetic actuation is performed according to the given output. The system as a whole transmits basic signals between neighboring elements over electric current and compressed air, which together provide energy to the entire installation. In this way each inflatable cushion works as a kind of interactive brick, which all together form a three dimensional wall structure that can dynamically adjust to actions of its visitors.

## 5. Future prospects

At present, described software developments of Protospace system and SwarmCAD are being tested and applied in more practical test case projects and installations. In the near future those two parallel developments will be seamlessly connected to create more intricate prototype projects of process-driven architecture, forming true complex systems evolving over the entire process of project development, from early conceptual up to building performance and maintenance.

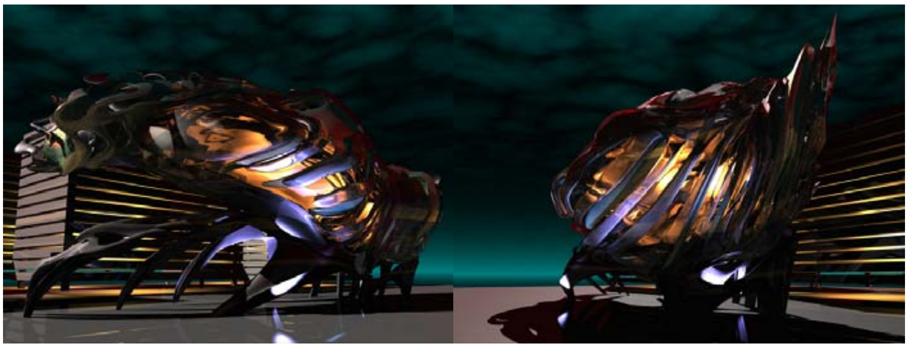

*Figure 9.* AlloBio - future vision of neuroarchitecture by Marcos Novak

If this path will prove successful, in a more distant prospect, the development may become the foundation for real transvergent architecture. This term originally introduced by Marcos Novak refers to architecture becoming a creative new fusion of disciplines. More intense integration of sciences in creation of process-driven architecture can thus eventually lead to further miniaturization of elements of architectural systems and to a much closer relation of architecture to biological sciences than it may now seem at all possible.

As Marcos Novak predicts, neuroarchitecture will be the next generation of architecture to come after the currently being born digital architecture. Future architects will use nanotechnology to create complex buildings made of neurons and atomic particles. Those half living beings will be able to reason on their own and will become real active partners in our lives.

## Acknowledgements

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