S A J _ 2012 _ 5 _

original scientific article

approval date 01 06 2013

UDK BROJEVI: 72.01; 691 ID BROJ: 202953996

4OF7.
ELASTIC DIARY OF THE RESEARCH BY DESIGN

A B S T R A C T

This paper will present a specific Research by Design setting at the University of Belgrade conducted by 4of7, the initiative which simultaneously encompasses the aspects of architectural practice, research and education. In the opening paragraphs 4of7 agenda will be discussed against three overlapping areas of the study: understanding and applying computational logic within the design process, the use of the prototypical models, and the investigation of the material processes. In the further body of the text, a sequence of experiments will be documented to demonstrate an ongoing architectural research, probing into the design workflow which employs elastic material performance to achieve highly versatile spatial organization and develop a non-geometric understanding of spatial environment. The study will explore the connection between two theoretical models, initially identified as the Field and the Network and material based studies in architectural design. *An abbreviated version of this text was presented at eCAADe conference "Computation and Performance" at TU Delft, September 2013.*

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KEY WORDS

4OF7
ELASTICITY
MATERIAL PERFORMANCE
SELF-REGULATING SYSTEMS
PROTOTYPICAL MODELS
PHYSICS BASED SIMULATION

SEA CHANGE

Changing one city for another, replacing corporate environment with an academic one and substituting the digital based workflow with what may be argued for as essentially an analogue one, could potentially lead toward significant transformation in person's thinking and perception of the architecture. If such circumstances were to take place, it would be reasonable to consider one's ability to adapt as a measure of success. The very notion of adaptability could then become central in many different ways and scales in that one's work. Equally, it may be reasonable to assume that any contextual change will inevitably trigger transformations of the internal way of thinking or even create an opportunity to establish unexpected and potentially beneficial angles of looking at the exact same issues related to the material processes, computational design and digital fabrication.

Changing London for Belgrade, and replacing the environment of ARUP and AKT with the one of the state run university have led to the establishment of "4of7", a non-institutional label for the initiative which encompasses seamlessly jointed aspects of architectural practice, research and education. Ever since 2007, the idea has primarily unfolded within the Master program at The Faculty of Architecture, University of Belgrade but has also taken excursions to other schools and visiting programs abroad. At present "4of7" agenda is based on several overlapping assumptions:

Firstly, there is an idea of computing without computers, brought forward by Kostas Terzidis: "Algorithms are not necessarily dependant on computers [...] This distinction is very important as it liberates, excludes and dissociates mathematical and logical process used for addressing the problem from the machine that facilitates the implementation of those processes".[1] He points out the difference between the terms of "computation" implying a way of resolving a problem, and "computerization" suggesting a way of storing and processing data with a computer. In other words, understanding and applying computational logic may be done with the use of analogue means such as physical models, diagrams and drawings.

Secondly, there is an urge to construct large scale models of the prototypical nature. This has been supported by the historical development of the incentive which started during the 1970s with the establishment of laboratories for full-scale modeling in many architectural schools across the Northern Europe. The initiative then suddenly died during the 1990s with the appearance of the first commercially available systems for computer aided design and then widely established belief that virtual modeling would be a sufficient replacement for the physical models. More recently, the very same ambition has come to surface once again with the development of digital fabrication laboratories and the need to establish links between the expanded means of digitally aided spatial imagination and the potency of numerically controlled machines for production. The approach is beautifully summed up within the idea of "Prototypical Architecture", presented in the treatise like description included in one of Marc Fornes's projects. Regardless of the resulting form, construction technique or the technologies involved, prototypical approach to architecture defines a specific way of architectural research, which encompasses both the aspects of design and construction. In "Persistent Modeling", Phil Ayers also points out the contemporary need to reconsider relationships between the three distinct phases of every architectural project: the design, the construction and the use.[2] The joint interpretation of both above stated concepts, offers a way to understand the process of modeling as an integral to architectural design as well as construction. This is to suggest that teaching and learning architecture could be based on the design and build approach, which blurs the distinction between the institutions of the studio and the workshop. Today, there are new and promising formats of researching in architecture encompassing practical/workshop approach which offers itself to better understanding of the elusive "Research by Design" paradigm in architecture. More meaning has been given to the notions such as experiment and laboratory in architecture. Further epistemological development of the ways of researching in architecture could once again open wide the debate if architectural model could be a self-sufficient and autonomous entity in contrast to its representational role in what is traditionally considered to be a complete architectural project comprised of the design proposal and the constructed object.

Thirdly, there is an interest in the reinvented understanding of the material and materiality in architecture. The idea may be traced back to the 1960s and the work of Frei Otto who spent his whole life studying the form-finding processes of nature. As explained by Barthel: "The form finding processes are those which given a specified set of conditions and following the prevailing laws of nature, gave rise to visible forms and constructions under experimental conditions. As they take place without human intervention, they are also termed autonomous formation processes".[3] Fuelled by the developments in the interdisciplinary field of materials science and engineering, a number of contemporary researchers in architecture are exploring matters of very own ability to organize itself and take structurally stable form. Increasing ability to compute and predict different material processes is an intriguing field of research. At this time, the focus is placed on the elastic material behavior and its role in the conception and construction of complex and adaptive spatial organizations, structures and environments.

FIELD AND NETWORK

At the turn of the twenty first century two North American based authors presented stimulating visions of plausible spatial organizations based on knowledgeable overviews of historic precedents in art and architecture. The first one was Stan Allen who depicted the Field Conditions[4] as bottom-up phenomena, defined not by overarching geometrical schemes but by intricate local connections. A few years later Mark Wigley described the Network Conditions[5] as an effect that cannot be designed, something that does not have an interior or exterior, a system of interlocking elements with many similarities to biological organisms. Instantly after their publication, both essays became an integral part of a great many agendas in architectural education and research. Yet, after a period of time, which now exceeds a full decade, we still feel obliged to pose the following questions: why do we still lack Fields and Networks in architecture? What are the material repercussions of these ideas? And how do we create spatial qualities promoted as such Conditions? In response, this paper will document a series of design experiments resulting in a series of prototypical models aimed at the development of architectural workflow based on the interpretation of the ideas from the essays “Field Conditions” and “Network Fever” through the notions of material performance and organizational properties.

MATERIAL PERFORMANCE AS SPATIAL ORGANIZATION

This study establishes connection between the two ideas, briefly described above and observed here as two theoretical models, and material based studies in architectural design, conducted as a sequence of experiments and resulting in the series of prototypical models. More precisely, the paper investigates analogous relationship between what is now broadly considered in architectural thinking as a complex spatial organization and the elastic performance of building materials.

Before we embark on the discussion about the possible importance of elastic material behavior in the formation of complex spatial originations, structures and environments, let us consider what it is that brings together two theoretical models adopted here as the departing point of the study. At first glimpse there is not much in common between the ideas of these two American authors. Yet, through a necessary level of theoretical abstraction, reducing the entire vision to the level of structural reasoning, we could just agree that, what binds them together is that both are equally remote from thinking of spatial order through geometric arrangements. They both embrace the logic of locally regulated interdependencies between their constitutional elements to achieve continuous growth and adaptability of their internal structure. They are likewise characterized by the lack of centrally imposed organization. Their form is distributed and non hierarchical. At the simplest level of comparison, a parallel may be drawn between points and lines of the Field model with the nodes and edges or vertices and connections of the Network model. Importantly, for the purpose of this study, two theoretical models are also complementary in their dependence on the similar but different local connections leading to the intricacy of the overall structure. The idea dates back to early critics of the geometric reasoning in production of the built environment. Lionel March and Philip Steadman were able to point out the importance of the "new mathematics" and relational reasoning in the understanding of complex spatial organizations.[6]

Present day interest in the material performance in architecture, fuelled by the increasing ability to compute and control material behavior, offers an intriguing way of thinking about complex spatial organizations. In relation to the number of key spatial features which have been accurately described by Allen and Wigley, this study recognizes the role of elastic material behavior as:

- an enabler of the diversity and interconnectivity throughout the construction of spatial models;
- an essential ingredient in the continuous growth of spatial structures;
- a mechanism for the systemic self-regulation in respect of any externally imposed influences.

In response, the study explores the ways of employing elastic material performance within the analogue modeling and the custom computation techniques in the search of diverse, interconnected, continuously growing and self-regulating spatial organizations, structures and environments.

ELASTOMER: THE MODELING MATERIAL

The experimentation begins with the selection of elastomers as our building material, above all for their form-changing capacity. Their main characteristic is elasticity, the ability to withstand transformation and return to their pre-deformed condition. Elastomers promisingly fit into the ideas of systemic self-regulation for their aptitude to adjust their internal structure according to the external stimuli. Interestingly, their chemical structure shares more characteristics with fluids and gases than with the solids that are most commonly used in the building industry. At the same time, by their behavior, elastomers resemble soft biological tissue able to change and adapt far easier than mechanical constructs which have been the dominant solution in the realization of responsive environments, up to the present day.

A brief review of the molecular structure of elastomers explains the resemblance better. They belong to the group of materials called polymers, characterized by long molecular chains which are linked among themselves with covalent chemical bonds. Under the normal conditions these molecular chains are conglobated, but when external stress is applied they become parallel to each other, allowing for the elongation of the material. Once the stress is removed, molecular chains regain their original configuration, relying on their covalent cross-linkages. Such a particular molecular structure makes elastomers known for the magnitude of their elastic range, defined with a very low stiffness threshold and extremely high yield point. Other building materials behave elastically too, but less visibly since their reversible deformation range is significantly smaller. Many of them obey Hook's Law of elasticity which states that strain is directly proportional to stress. Consequently, mathematical description of a material's tendency to be deformed elastically is defined through the elastic modulus, equal to the ratio of tensile stress to tensile strain. For elastomers Hook's Law is applicable only approximately because their hard-to-control chemical structure is sensitive to loading rate and many other external factors. It is important to note that the performance of an elastomer based materials is highly dependent on the conditions of their environment, such as temperature and humidity, and also highly susceptible to loading rate and direction of any physical force that could be applied, such as wind force.[7]

GEOMETRIC AND ELASTIC PROTOCOLS: THE MODELING TECHNIQUE

After having provided an account of elastomer based materials and their elastic behavior, this paper will now focus on a more difficult part of the research which deals with the problem of how to employ and cognitively comprehend reversible deformability as a generative mechanism directly within the design process. For the purpose of efficient research flow, it is kick-started the experiment with a physical modeling technique and the use of affordable, recycled and omnipresent form of an elastomer based material: the rubber-band. The proposed model-building technique is founded on an accumulative assembly of components according to two parallel sets of principles. The first one is the algorithmic logic of consistent growth, whereby components are combined according to a geometric rule-based system; its logic is to be exhibited in a series of steps leading to the growth of the overall structure. The second set of principles is equally important but infinitely less apparent. As it only gains momentum through the modeling process while initial geometric logic dissipates and becomes restrictive to further growth; it is related to inherent properties of the proposed building material, chosen for its intrinsic or chemical structure that permits change and diversification between previously identical components. Through elastic material behavior, the entire physical model acquires the autonomous ability to recalculate itself in real time according to any amendment or the addition of a new component.

At the outset, the elasticity is employed intuitively in the form-making process, but throughout the experimentation, the understanding of its formative potential gradually progresses from the approximation toward more explicit and parameter-based control achieved through custom computation. Along with the geometric rules, the nature of the elastic deformation is translated into yet another set of rules, to form an algorithmic protocol based on Hook’s Law. The manifestation of elastic behavior is observed via the elongation of the individual components according to the changing amount of stress imposed on them and relative to the material’s tendency to be deformed elastically, or its elastic modulus.[8]

ELASTIC DIARIES

The experimentation is conducted as a sequence of design workshops resulting in a series of prototypical models. Over a two-year period, four workshops were held within the scope of this research. Approximately sixty architectural students from different architectural schools participated. The initial workshop took place at the University of Belgrade within the framework of the Graduate Design Studio Course. The exercise was carried out with sixteen participants, over a short period of time and with an aim to initiate thinking about adaptable spatial configurations and introduce appropriate design techniques to be utilized throughout the semester. Students were asked to use rubber bands and construct spatial assemblies by exploring algorithmic logic and employing rule-based system to achieve geometric complexity. In parallel, students were suggested to explore elastic material properties while assembling their models. The task proved to be challenging as the material lacked stiffness and any spatial configurations had to rely on the surrounding environment to achieve structural stability. At the same time, the inconsistent chemical structure of the material proved to be intriguing to students. Its potentials in structural and formal thinking became apparent through model building, to the extent that the inconsistency of the material structure lent itself to the title of the entire workshop series. As a result, the students produced a number of models which were able to respond to externally applied force by changing their geometric configuration and resuming their initial form thereafter. The process of structural change was recorded with a time lapse sequence of photos, which were composed into short films by the students (Figure 01).

Almost a year later, the second workshop took place in Tehran within the Visiting Program, a platform created by the Architectural Association to further extend its educational setting through international engagement and collaboration with a diverse group of local partners and schools. At the outset, participating students were shown the results from the previous workshop and were asked to respond by making their own models using the same material and similar techniques. With a different working regime than the workshop in Belgrade and a formidable level of commitment, students produced comparable results on the third day of the workshop. With ten days remaining, this was an opportunity to expand the agenda and move toward the making of larger structures and full-scale models. Students were grouped into five teams based on social ties, but also according to the common threads identified in the models they had produced in the opening stage of the workshop. Two teams opted to substitute rubber bands with other elastomer based components, while the other three groups decided to continue with the same material. A four-member team (Amir Reza Esfahbodi, Abolhassan Karimi, Imman Shameli and Mohammad Habibi Savadkuhi) working closely with their tutor, proved to be the most effective and able to assimilate structural reasoning into their modeling technique. As a result, in the concluding stages of the workshop, they produced two large-scale prototypes. The initial models made of rubber bands were replaced with models composed of more durable elastomer strips, measuring 100 mm in width. The second prototype, being the larger of the two, reached the height of 11m. Similarly to the models from the first workshop, this model was designed to respond to externally applied force by changing its geometric configuration and then resuming its initial state after the action, yet now this was done in relation to the force imposed by the weight of a grown

Figure 01. Model from the series “Inconsistencies v.01”, University of Belgrade 2010. Student Bojana Gocanin.

Figure 02. Prototypical model “Inconsistencies v.02”, University of Tehran, Architectural Association’s Visiting Program, 2011. Students: Amir Reza Esfahbodi, Abdolhassan Karimi, Imman Shameli and Mohammad Habibi Savadkuhi.

person. To everyone's amusement, at the final day of the workshop, visitors and fellow students were invited to test the model by swaying in it with the amplitude of 3 meters (Figure 02).

Later on the same year the third workshop took place, although it was organized differently from the first two. The most important change was that students were not asked to create their own models but to participate in the making of a single structure based on the established design protocol. There were neither drawings nor computer models made prior to the construction process, only verbal instructions formulated from the knowledge gathered in the previous workshops. Namely, a particular failure from the previous workshop in Tehran, a never completed model, was recalled for its construction technique. What had been started there, together with the understanding of advantages and disadvantages of rubbery materials acquired throughout construction of other models, became the design protocol for the growth of the structure. The event took place in O3one art space in Belgrade (Figure 03, 04).

The construction started simultaneously from five points in space from which a number of tentacles were established in relation to the structural considerations of the most suitable supporting points within the given environment. From there the structure grew in a systemic way through the insertion of a new tentacle at the mid-point of an existing strand. A total of sixteen students worked on the model simultaneously and independently, or in small teams of two or three members. As anticipated, after a number of recursive steps, the initial rule based growth process became less apparent and had to give way to a new logic related to elastic material behavior or the inherent property of the employed building material. As noted by Branko Kolarević, one of the most prominent characteristics of the structure was the distinction between the initial and the emergent set of rules employed throughout the construction process.[9] Such emergent rules are directly related to the material performance. Through the effect of elasticity, the entire physical model acquires an instantaneous ability to recalculate itself according to any amendment or addition of a new component. At any moment during the growth process, the overall stability of the structure was reliant on the multitude of local conditions and the ability of initially identical modular components to react to tension forces and go through a process of gradual adaptation according to continually changing structural circumstances. When presented with the images of the end result of the workshop at O3one Art Space in the context of much broader conversation on relevance of network organizations in architecture, Marc Wigley was able to point out the resilience of the system by looking at the model, which he then recognized as an essential enabler of the curious spatial condition defined by the lack of distinction between the interior and the exterior of the structure created.[10] In reference to that, we would like to suggest that prototype “Inconsistencies v.03”, resulting model of the third workshop, could be simultaneously examined as a specific environment created inbetween elastic lines and an object with its own structural logic. We can also observe variations in the density of the structure. Closer examination of different parts of the model reveals their individual properties. Majority of segments with higher densities of elastic lines resemble objects with their own identities and boundaries, while other segments positioned closer to the existing walls reveal features of the environment allowing visitors to walk through them.[11]

Exactly 12 kg of yellow rubber bands measuring 70mm in length and 5mm in width were employed as construction components of the model. In addition, approximately 8000 metal clips were used as joints between bands. The resulting structure occupied the room with a foot-print of 50 square meters and a height of 3.5 meters. It took five days to complete the assembly. The intention for the next prototypical model was to build with more parts, from more durable materials and at a larger scale. Simply put, the idea was “the bigger the better”, with an aim to close the gap between the model and the actual building (Figure 05).

Equally defining was the ambition to construct the structure in the open to include the influence of the atmospheric conditions such as temperature (C), humidity (%), wind force (m/s) as well as the influence of the material performance on the rule-based geometric protocol of the model building or structure’s growth. The fourth or the final workshop was held in the pool-like space with exposed concrete floor and walls. At the time, the given site was formally under construction court-yard of the newly refurbished historic building in Belgrade. The structure was built according to the plan tested in the previous workshop based on the design and build protocol and the participation of sixteen students from the University of Belgrade. Instead of the rubber bands, rolls of elastomer based strips were used and in the place of metal clips there were purpose designed joints made of two laser-cut, steel plates and two plastic ties to hold them together. The shorter span between two ends of the structure was thirteen meters and its height reached just over 5 meters. Due to the size of the model and the need to establish joints at high altitudes, the assembly process was significantly slower than the previous time. But after several steps of construction following the rule-based protocol which implied

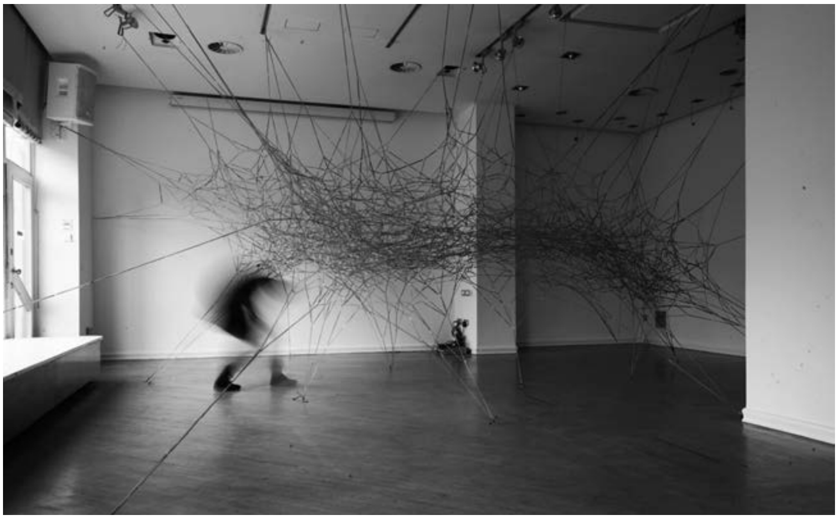

Figure 03. Prototypical model “Inconsistencies v.03”, O3one Art Space 2011. Photo Ana Kostic.

Figure 04. Prototypical model “Inconsistencies v.03”, O3one Art Space 2011. Photo Ana Kostic.

Figure 05. Prototypical model “Inconsistencies v.04”, Belgrade 2012. Photo Ana Kostic.

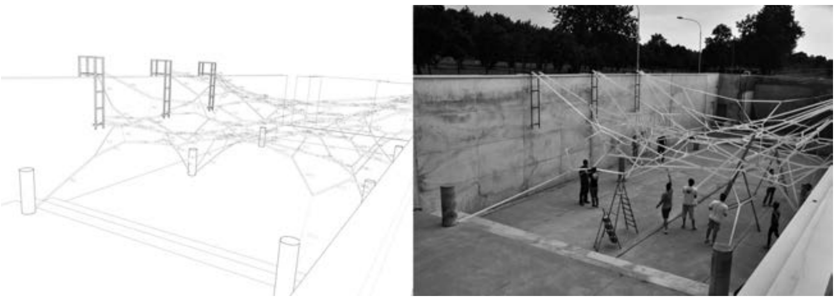

Figure 06. Feedback loops: digital vs. analogue model of the elastic structure.

Figure 07. Design tool: Spider for Rhinoceros splash screen

continuous subdivision of the existing spans with the insertion of the new ones, one was able to observe importance of the elastic material behavior and take note of the influence of oscillations in temperature and wind force upon the entire geometric configuration of the model. Importantly and in contrast to the previous workshops, this time it has been relied on the digital model and the simulation of the material and physical processes to predict, prepare and coordinate construction on site (Figure 06).

Comparison between the digital and the physical model was done and recorded nineteen times during the assembly process. During the first seven steps the growth process followed the digital model, while the remaining twelve steps were carried out with the reverse logic whereby digital modeling followed the activity on site. Minimal dimensional discrepancies at different stages of the assembly process proved the validity of the method to compute material and physical processes and their implication on the geometric configuration of the structure.

CUSTOM COMPUTATION FOR THE MODELING WITH THE MATERIAL PERFORMANCE

One of the concrete outcomes of the exploration is the specific software extension produced by the authors of this paper in collaboration with the Group for Mathematics, Architectural Geometry and CAAD at The Faculty of Architecture, University of Belgrade. Custom programming was done by Bojan Mitrovic. The software created has now been made available, in the form of the plug-in for the Rhinoceros platform, under the brand name "Spider" (free download from food4Rhino website 2012).[12] Its purpose is to enable designers to maintain an indirect control of complex spatial models, based on the use of two parallel sets of algorithmic protocols which define: a. geometric logic and b. intrinsic material behavior. The tool enacts simulation of elastic material behavior throughout the process of geometric modeling and provides for more precise inclusion of material performance throughout the design process. It contains features for parametric control of reversible deformation range and elastic modulus, to allow iterative testing and enable parallel consideration of different building materials (Figure 07).

The tool also provides for the parametric control of environmental parameters, including the wind force and direction. The programming approach rests on the use on the particle-spring systems commonly used for creating physics based simulations. It has been anticipated that the tool created for the purpose of this investigation might be applicable to other research related to form-finding and optimization of spatial structures, as well as the strategic planning of spatial organizations.

CONCLUSIONS AND PROSPECTS

A number of prototypical models have been produced to test the practical and theoretical dimensions of the design approach which employs elastic material performance to achieve a highly versatile spatial organization, initially identified within the ideas of the Field and the Network Conditions (Allen 1997; Wigley 2001). The study has introduced specific workflows in which the architect assumes only an indirect control of the model, allowing for the more open negotiation between material performance and the environmental influences in the design process. The research was unfolding as a series of feedback loops in which material performance, intuitive decision making and computational tools were all combined. Material testing was conducted in parallel with the formal modeling and the development of the custom computational tools.

Prospects for the development of the research presented in this paper include two plausible routes. The first one would be pragmatic in its nature and could relate to the continuation in production of prototypical models with the purpose of developing a specific structural solution. The particularity of such a system would be based on the immediate inclusion of building physics during the process of architectural design. If we accept elasticity, as one of the key characteristics of building materials, we can then begin to evaluate the relevance of designing and building spatial structures according to the principles of elastic material behavior. Design tools and workflows developed during the research with elastomer based assemblies may equally be applied to building materials with less apparent elastic properties. Prospects for further research could include more efficient uses of wood, steel and other materials used regularly in the building industry. Iterative modeling techniques, use of prototypical models and better prediction of the material processes are seen here as means for understanding and employment of the elastic material behavior in the design process.

The second route is related to strategic thinking of spatial organizations and would be inclined toward contribution in the development of the systemic approach in architectural design. As it has been pointed out, in the example of the model “Inconsistencies v.03”, the understanding of elasticity as a capacity of a reversible change, has been transposed from the material behavior into the characteristics of the overall structure. Roderic Lakes (1993) points out that that many natural and man-made materials, including polymers, exhibit structures on more than one length scale and concludes that structural hierarchy can play a large part in determining the bulk material properties.[13] In the research documented in this paper, Lakes' idea of the hierarchical transposition of structural properties through different scales of material was expanded to include the transposition from the material to the entire structure of the prototypical model. Prospects for further research include the aim for better understanding of structures with the capacity of self-regulation or the ability to maintain stability or constancy of the internal organization in spite of the changes of their environment. Tested workflows provide for highly adaptable design solutions that could easily be adjusted to different locations while keeping their material, structural and organizational logic. With the knowledge acquired through further experimentation, we would like to continue exploring the importance of elasticity as a structural change at the material level, within the boarder significance of architectural strategies.

NOTES

N.B.

The documented study combines research and teaching efforts; it has been planned as a collective effort and would not be possible without contribution from our students from The University of Belgrade and Architectural Association, Visiting School. The authors would like to thank Branko Kolarević and Nate Kolbe. Following is the full credit list:

Inconsistencies v.01: Djordje Stojanović (assistant professor), Milutin Cerović (teaching assistant), Snežana Zlatković, Milica Tasić, Ružica Jovanović, Andjela Karabašević, Ivana Pepić, Bogdan Obradović, Milan Karaklić, Bojana Gočanin, Nikola Samardžija, Natalija Bogdanović, Jasna Sorgić, Danica Marinković, Ivana Jovanović, Natalija Usendić, Andrej Žikić, Aleksandra Samardžić (students).

Inconsistencies v.02: Djordje Stojanović, Maryam Pousti (tutors), Amir Reza Esfahbodi, Abdolhassan Karimi, Imman Shameli, Mohammad Habibi Savadkuhi Arefeh Fathi, Smaneh Ghasempour, Sepideh Monkhtari, Sajedeh Madani, Parisa Hassanzadegan, Shaghayegh Taheri, Ali Ghorbani, Ali Kashfi, Sepideh Ghaemmaghami, Khashayar Shafagh, Oveis Shahnaee, Ali Reza Shojakhani (students).

Inconsistencies v.03: Djordje Stojanović (assistant professor), Milutin Cerović (teaching assistant), Milica Tasić (assistant), Ivana Radović, Katarina Mercep, Marija Pop-Mitić, Danka

Sijerković, Jovan Pucarević, Dea Kolaček, Miloš Simić, Emilija Zlatković, Milan Katić, Dušan Tasić, Sonja Elaković, Ana Todosijević, Marko Vukajlović (students). Photo: Ana Kostić.

Inconsistencies v.04: Djordje Stojanović (assistant professor), Milutin Cerović (teaching assistant), Milan Katić, Milica Tasić (assistants), Nikola Milanović, Ivana Radović, Katarina Mercep, Marija Pop-Mitić, Danka Sijerković, Jovan Pucarević, Dea Kolaček, Miloš Simić, Emilija Zlatković, Dušan Tasić, Ana Todosijević, Marko Vukajlović, Nevena Bjelaković (students). Custom programming by Bojan Mitrović, Group for Mathematics, Architectural Geometry and CAAD at Faculty of Architecture, University of Belgrade. Photo: Ana Kostić.

1 Kostas Terzidis, *Algorithmic Architecture* (Oxford: Architectural Press, 2006), 37.

2 Phill Ayres, "Persistent Modelling – reconsidering Relations," in *Persistent Modelling, Extending the Role of Architectural Representation* (London: Routledge, 2012), 1-9.

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5 Mark Wigley, "Network Fever," *Grey Room*, MIT Press Journal, #4 (2001), 82–122.

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