Digital Form Finding

Generative use of simulation processes by architects in the early stages of the design process

Yasha J. Grobman[1], *Ruth Ron* [2]

[1]*Faculty of Architecture and Town Planning, Technion, Israel Institute of Technology, Israel,*
[2] *School of Architecture, University of Florida, USA*

[1]*http://architecture.technion.ac.il/faculty.php?pi=481,* *http://tx.technion.ac.il/~tcode/*
[2]*http://www.dcp.ufl.edu/arch/main/faculty/ron.htm.*

Abstract. The paper presents performance oriented approaches to digital form finding which stems from the lines of research on performance and morphogenesis in architectural design.

The main contribution to the earlier research is threefold; it examines the potential of the presented design processes to integrate interdisciplinary approach based on the use of simulation tools by architects or direct data exchange between simulation tools and design. Secondly, it explores new methods to generate initial architectural form based on performance information that apply to both building scale and urban scale, and lastly, it develops the theoretical framework on the ramifications of employing simulation technology and techniques in architectural design.

Keywords. Form generation; performance; simulation; parametric design; form finding.

Introduction

Traditional modes of form creation have given significant weight to qualitative, cognitive and perceptual aspects of the architectural form. Throughout the history of architecture, this idea sustained logocentric modes of operation and theories, which in turn promoted the image-based approaches to form, such as typology and shape grammar. Starting from the late 1960's, the introduction of computers to architectural design ushered in the possibility of using computers to generate architectural form using quantitative data.

The early stages of performance and morphogenesis research were promoted by researchers such as (Caldas et al. 2003), (Frazer 1995), Hensel et al. (Hensel et al. 2006), Kolarevic & A. Malkawi (Kolarevic & A. Malkawi 2005), Monks et al.(Monks et al. 2000), practitioners such as Greg Lynn (Lynn 1999), and implemented in design tools and methods such as eifForm (Shea 2004) and Flux Structure (Sasaki et al. 2007). A critical review on architectural computer based form generation and performance in architectural design can be found in Grobman et al. (2009a).

Many contemporary architectural practices use simulation results in an "after-the-fact" manner for design evaluation purposes. In this kind of a design process, the solution's adherence to performance criteria is examined, usually by specialized consultants, using simulation software. The design is then modified according to the results in order to improve upon it. However, changes at late design stages are generally very limited, hard to implement and expensive.

This paper discusses digital form finding processes in which computer simulation tools are used in a generative or "before-the-fact" manner (Kolarevic, 2004), that is, to generate 3D architectural forms directly from performance information. Form which is generated this way adheres by definition to the specified performance criteria that were used to generate it and does not necessitate reevaluation. This can augment the general performance of a building and promote a more efficient design process, while producing a form that embeds a larger amount of performance-related information.

The paper argues that the suggested processes could be applied to various scales, from a building detail to urban design. The argument is presented and discussed via two different approaches to performance-based form generation. The first approach concentrates on the possibility to use existing simulation tools by architects to generate the initial form or design space directly from performance simulation. This could be done by using direct data exchange between the simulation tools and the design or via mediators such as performance envelopes (J. Y. Grobman, Yezioro & Capeluto 2009b), or performance gradient maps. This approach is presented throughout case studies that used visibility, circulation, structural and acoustic simulations to generate an initial architectural form.

The second approach involves customized tools and techniques development that allow designers to generate form based on specific programmatic and performance demands. The development of a design using this approach necessitates, probably, resources beyond those exist in an average architectural firm and might open new opportunities for collaborations with experts from other disciplines early on the design process.

Performative generative architectural design

One innovative aspect of the early stages of this discourse was the relationship between performance-related criteria and architectural form. A general discussion on performance and the shift to Performalism in architectural design can be found in Grobman & Neuman (2011). Initial attempts to use performance criteria for form generation include architects such as Greg Lynn (proposal for the Port Authority pedestrian bridge competition (Lynn 1999)) and Franken Architekten , (design of 'Dynaform' project, Schmal & Flagge 2001). These proposals used animation software to simulate variant movements through space, such as pedestrians, cars etc.

In the Port Authority project, a particle animation used physical calculation to simulate dynamic movement, elastic bounce, attraction and gravity, and the trajectory of the animated particles became the tubular structure of the building (Lynn 1999). Although it uses a sophisticated calculated simulation and directly generates form in the same modeling environment, the simulation itself was inspired by movement and freely interpreted it as a method to achieve formal complexity, rather than for optimization and control over the behavior of an architectural form.

Later research within this realm in the early 2000's promoted an interdisciplinary approach that examined new possibilities in performance-oriented design due to the increasing connectivity between tools and ideas coming from engineering and architecture ((Kolarevic 2003), (A. M. Malkawi et al. 2003)) and promoted material oriented approach (Hensel & Menges 2007)

Generative use of simulation processes by architects

The possibilities for generative architectural design have advanced dramatically in recent years. Only a decade ago, parametric generative design was mainly limited to academic research and large architectural firms that had the resources to employ computer programmers (İt refers to architectural firms such as Foster + Partners which used in-house programmers in projects such as Swiss Re headquarters tower in London). Today, with the assimilation of software such as Grasshopper (See http://www.grasshopper3d.com/) and Paracloud GEM (See http://paraclouding.com/GEM/), parametric generative modeling had become popular and building with parametrically design elements (usually building envelopes) are becoming abundant.

The link between parametric design tools and design processes which are based on performance simulation is still not direct. First, the architect has to export preliminary data of the site and building form into the simulation software, which may require substantial geometric simplification, or recreating it again in that environment. Secondly, in order to use performance simulation results as generative tool, data has to be imported back from the simulation platform into the design environment. This cumbersome process limits the iterative nature of this design method.

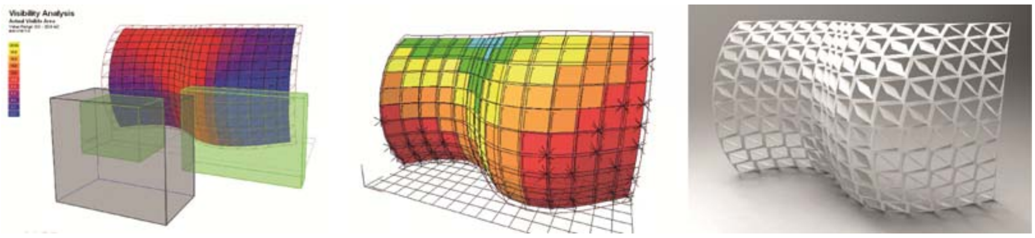

Figure 1

Visibility analysis in Autodesk Ecotect (left). Generating parametric building envelope based on the analysis results in Paracloud Gem. (middle and right)

Generating building envelope based on visibility analysis FIGURE 1 is an example for this type of design process. It illustrates a parametric model that generates a building envelope in which the openings generated parametrically in relation to the visibility analysis of the façade. The analysis examines the visual connection between two surfaces/buildings. The visual exposure simulation in this case was created with Autodesk Ecotect and then imported into the design environment (Paracloud GEM) as a pixelated gradient map. Similar approach which employs gradient maps could also be used with other performance parameters such as level of illumination, wind/air velocity (ventilation) both in building and urban scales.

An additional example is the use of circulation information to generate an initial form for a public space. It started with particles emission sources setup that was based on site analysis and design decisions regarding expected and desired main circulation axes, and defined the number and directions particles emitters. Following the initial setup, particles are released to the design environment and numerous simulations are performed.

The first image from the left in FIGURE 2 shows a single frame from a simulation run where each cross represents a particle/person, while the second image from the left shows a compilation of all the frames into one image (the dark and light colors represent different times of day). The tracing process that is presented in the following third, fourth and fifth images from the left is a completion of all the paths. It forms emerging patterns, which were in this case areas of concentration of circulation paths. The initial extruded volumes, presented in the right hand image, represent the initial formal definitions of an enclosed space for more detailed architectural design. This design space enfolds areas where concentrations of pedestrians are expected.

This example present again a design method that is utilising existing simulation tools, with a 'before the fact' simulation, and assisting design decisions at urban scale. İn this case, since the particles simulation was created with Autodesk 3Dmax, the performance simulation and the architectural form generation and design can share the same platform but do not connect in real time.

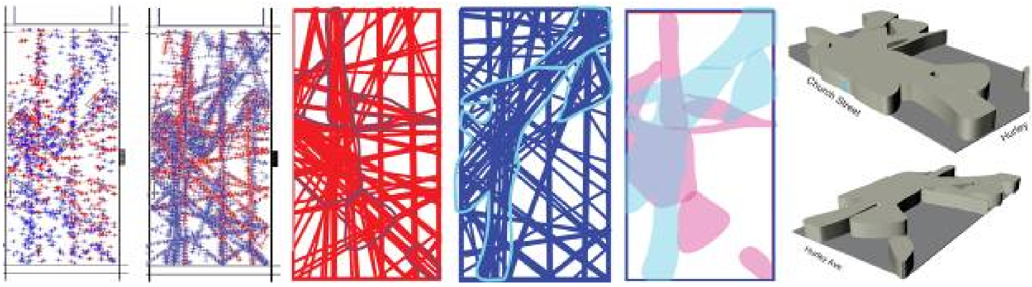

Figure 2
Generating building envelope based on visibility analysis

The following examples present a different approach to simulation based form finding.
The first case study develops a design method that generates an initial form for a shading structure. The structure form is defined by programmatic demands for a desired shaded area, based on three parameters: number of users, their spatial distribution and the time in which the shade is needed.

The initial form generation stage employs a custom designed algorithm that was developed in MathLab software to generate a preliminary envelope [FIGURE 3]. A second form finding process that employs gravitational cloth simulation and is based on compound material properties uses the input from the first process to generate a secondary envelope. It produces a secondary form while optimizing the position of hanging points for the manufacturing process.

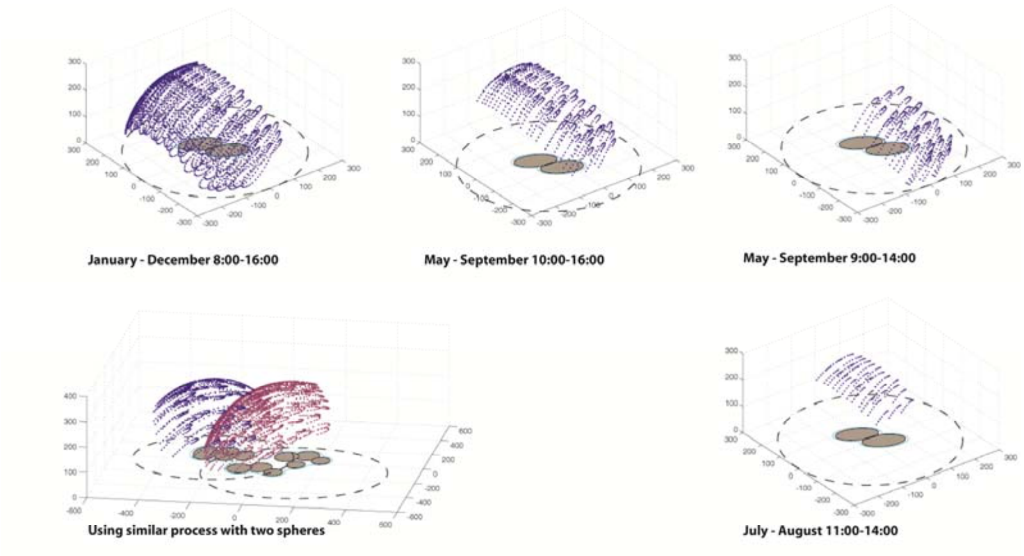

Figure 3
Examining the influence of different area and timeframe definitions on the shading envelope

The secondary envelope is further examined for structural stability, tension and stress. The information from the structural analysis is used to perforate the form in structurally redundant areas and to reinforce the structure in problematic areas [FIGURE 4].

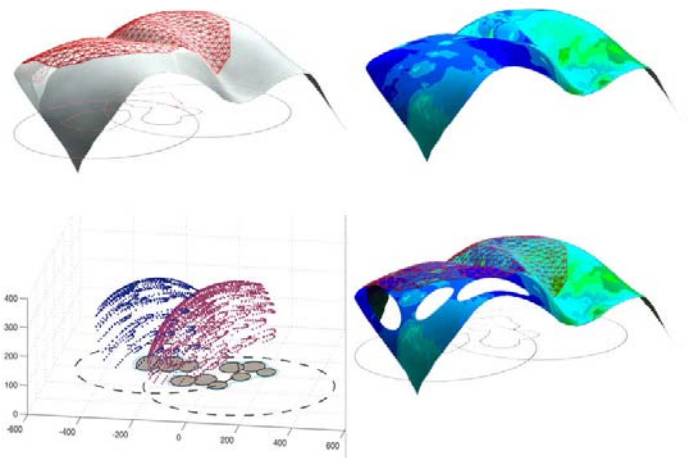

Figure 4
Left down: initial point cloud generated envelope. Left up: merging the initial envelope with a second envelope that was generated in a gravitational form finding process. Right up: structural load/tension analysis. Right down: perforating the envelope according to the structural analysis and other programmatic demands.

The envelope is manufactured as a monocoque structure using compound materials. It employs multi layer fiberglass fabric which is hardened by an epoxy resin in a heating/ curing process. The fiberglass fabric is cut and perforated using the information from the secondary envelope. In order to avoid the traditional use of molds in the manufacturing process the curing process is performed while the fabric is hanged upside down from predefined points. In the manufacturing process, polyurethane is injected between the fiberglass fabric layers for structural reinforcements.

The next case study examines the possibility of using data from traffic and acoustic simulation to generate an urban scale site plan and an initial architectural form in a highly problematic acoustic environment.

The project proposes a redevelopment plan for the “Bridge District” in downtown Orlando, Florida, by reconnecting the east and west sides of the city underneath an elevated highway. The site, currently underused, measuring approximately 10 acres, and a target for a road extension, has height limitations, vehicular noise, pollution and lack of direct sunlight.

Earlier examples for using acoustic performance as a key design driver by utilizing parametric modeling methods are discussed in Caldas et al. (2003) and in Peters (2010). In the first article simulation is used as a generative method at an early design stage but the dynamic form generation process is limited only to the size, position and angle of acoustic boards, and does not influence the architectural form itself. The second example presents the Smithsonian Institute Courtyard Enclosure in Washington D.C by Foster + Partners, where a total area for acoustic absorbing material placed on the roof structure was calculated as a parameter in a form generating algorithm that computed design variations. Although different platform were used for analysis and for the design, which required a data exchange process, the design is mainly automated and developed custom tools, similar to the shading case study.

After an extensive survey of building facades, traffic counts and sound measurements, several 3D models of the Orlando site were created: first a low-polygon 3D model of the area with high resolution maps. The 3D model was imported into virtual reality software named UC-Win/Road to generate a traffic simulation and animation (The detailed simulation data rely on UC-Win/Road traffic generation algorithm that was created by input of average of cars and car types as collected by combining in-site traffic counts and online data resources). The 3D model and a list of frames from the traffic simulation, capturing cars x/y/z location, type and speed were extracted and fed into an acoustic simulation. Comparing to a typical architectural acoustic simulation that uses 2D site plans and annual traffic average, this example adds detailed geometry and traffic data.

The major acoustic challenges at the site are airborne and structural traffic noise. Noise-reducing barriers are most effective when enclosing space completely; however, the desire of the project is to have an open park. Based on Egan (1998) and Harris (1998), several basic acoustic design strategies were defined to reduce noise and control reverberation: acoustic walls to envelope the road, structurally independent acoustic skin on the underside of the highway, and partial acoustical berms to block direct paths from noise sources. Lastly, surface treatment is used to reduce reverberation.

The acoustic generative from finding process in the project operates at two scales. At an urban scale, the simulated noise maps and defined program acoustic criteria were used for the initial placement of functions in the site and the creation of the master plan. A program that required quiet conditions was placed in the area with less simulated noise and vice versa. This plan was used to identify problematic zones that would require acoustic intervention [FIGURE 5].

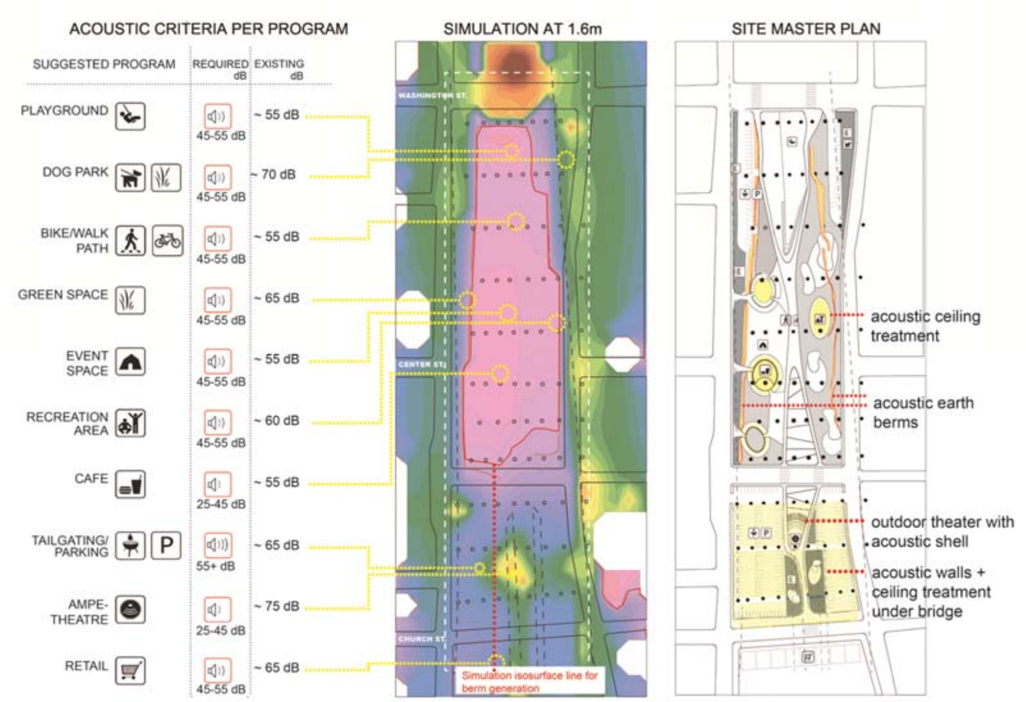

Figure 5
Acoustic criteria definition + simulation results and deficits (left) master plan (right)

The next level, or the architectural scale, combines the acoustic deficits identified in the master plan with the noise reduction strategies defined earlier. In the southern half of the site, where the greatest pedestrian traffic is expected and where an outdoor theater is located, the gap between predicted and required noise is the greatest. In this area the more extensive noise reduction strategies were used by enveloping the elevated road above and underneath and by blocking the acoustic line-of-sight in the theater area. In addition a noise absorbing surfaces were designed [FIGURE 6]. The design constrains include structural isolation to avoid structure borne noise passage, material type and thickness calculated based on Egan’s (2007) guide , blocking of acoustical line-of sight for seating audience and placement of specific absorbing material in the surrounding area to minimize noise reflection.

In the northern part, earth berms were designed to block acoustic line-of-sight in areas that require interpersonal communication. The form generation process used 3D isosurfaces from the acoustic simulation to sweep a designed berm profile. Based on secondary simulations, pieces from the continuous berms shape were subtracted, with a goal to improve daylight conditions and accessibly to the site. The generative process is done with the following constrains and parameters: the barrier cannot create completely enclosed areas, the acoustic ‘line-of-sight’ is set to an average ear height of a standing and sitting adult, the width and dimension of the thin wall barriers and berms were calculated based on Egan’s recommendations (2007) and no parallel walls can be constructed to avoid reflection and standing sound waves that increase the noise.

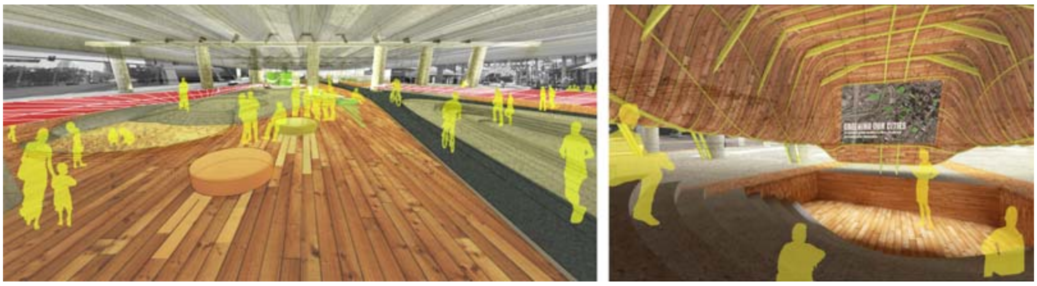

Figure 6: Acoustic treatment using acoustic barrier, berms (red) absorbing treatment (left) and theater shell (right)

The generative methods embeds within them simulation results and the defined parametric constrains. The project used existing simulation and modeling tools and combine automated and manual processes.

Discussion and conclusions

The move towards performance-oriented design and the use of simulation processes in architecture raises contradicting speculations regarding the future of the profession. On one hand, the ability of architects to use simulation data in design environment and the possibility of direct data exchange between design and simulation tools elevate the architect’s position within the industry in terms of responsibilities and influence. On the other hand, a direct use of performance simulation increases and the complexity of the parametric design models require knowledge which is beyond the current scope of the architects’ education and could support an argument that engineers are the new architects (Fortmeyer 2006), namely, the complexity of the multi criteria simulation scenarios would require that engineers and computer programmers will be responsible for the initial form generation process.

Nevertheless, current software development, such as Paracloud GEM, Rhino Paneling Tool and Rhino Grasshopper plug-ins allow non- programmers to automate design processes and parametrically control complex forms and patterns. These, accompanied by an enormous number of bottom-up online software training resources, may point to a direction that software development is closing the describe gap, and in the future architects will have greater performative control over their design. On the other hand, as initial performance based architectural projects appear; there is a desire to increase their complexity to incorporate multiple simulations and criteria, which would probably increase the need to involve other disciplines in the design process. These developments also blur the definition between ‘existing simulation tools’ and ‘custom tools’, as presented along this paper.

Although it seems that these changes do not do away with the need for pedagogical changes in architectural education and a reexamination of the collaboration between architects and professional advisers during the initial stages of the design, the direction in which the profession is heading is not clear yet. What is already clear is that the near future will possibly present highly developed, precise and fine-tuned initial performance based architectural form.

One of the main limitations in the current use of performance simulation by architects in the initial stages of design is the lack of direct connection between the simulation results and the generative parametric architectural model. In a Parametric modeling method, forms and patterns correspond to criteria set values and allow designers to examine numerous design alternatives in a short time. Developing a direct data connection will allow designers to faster examine the ramifications of the reciprocal link between form and performance, which today is mostly done manually. The manual process of importing data to the design space in a burdensome process has a direct influence on the amount of alternative that the design team is able to examine under typical time constrains. Moreover, although the connection between design and simulation will necessitate higher level of knowledge, which is currently unavailable, it will also allow designers to experience an iterative process of trial and error which will contribute both to creativity and the understanding of a solution's performance.

The direct connection between simulation and design tools that is suggested by the second approach is a step towards non-linear design process in which design directions and alternatives are generated, presented and evaluated simultaneously, and in real time. Moving towards non-linear modes of design arguably increases design creativity by allowing generation and simulation simultaneously, with a greater number of iteration and variation of design alternatives (Grobman et al. 2009b). However, evaluating these alternatives, using both internal performance criteria and external architectural criteria is still done manually by the designer (for more information on internal and external criteria see Grobman et al. (2009b)). A further development of automated process in connection with performance based design, both for design and evaluation, in the design environment could present an important contribution to this domain.

The idea of using early stage simulation for form generation, which inverse the traditional design process, tries to integrate numerous developments in architectural practice, technology and theory into a singular method. It is based on the assumption that as opposed to the situation in previous decades, the information coming from many current analyses, optimization and design applications can be now linked and synthesized into interdisciplinary platforms based on direct data exchange. The suggested approaches would help to equip architects with means to meet the huge challenges facing the built environment.

The current research only scratches the surface of the potential of performance based form finding in architecture. It presents the challenges and struggle of this innovative approach. We hope that this research, as an inclusive design approach, has a potential to improve the design and performance at multiple scales of future buildings, neighborhoods and cities towards a more sustainable world.

Acknowledgments

The first case study was by the students Slavik Chokler, Keren Doviner and Chen Shoham for a graduate course lead by Yasha J. Grobman.

The second case study was done within the framework of a graduate workshop in Florida University (UF) School of Architecture that was led by the authors. The case study was developed by the students: Ni Guan, Wylie Gunn, Daniel Gutierrez, Margaret Hoffman, Lauren Insalaco, Ji Woong Kim, Jamie Krissoff, Yang Liu, Nick Lowe, Chris Neukamm, Angel Ortiz, Alex Ruhnau, Joana Thurston, Hannah Wharton, Helen Wong. The third case study was developed by Yasha J. Grobman together with Arielle Blonder, Guy Austern, Mushit Fidelman, Tzach harari and Guy Bunin.

The forth case study was developed Ruth Ron with contributions by Matthew Swarts,’ Imagine Lab’, Georgia Institute of Technology, and Yasha Grobman, Technion, Israel. Research assistants: Adam Betcher, Lucky Tsaih, Arseniy Shabashvilli, Steven Tenzel, Charles Gurrey, John Guinn and Paul Giese. Animation by FORUM8AZ, www.forum8az.com.

References

Caldas, L., Norford, L. & Rocha, J. 2003,. 'An evolutionary model for sustainable design', *Management of Environmental Quality: An International Journal*, 14(3), pp.383-397.

Egan, M. D. 1988. *Architectural Acoustics*, McGraw Hill.

Fortmeyer, R 2006, 'When Less Powers More', *Architectural Record*, 194(12), p.104.

Frazer, J 1995, *An Evolutionary Architecture*, Architectural Association Publications.

Grobman, YJ, Yezioro, A & Capeluto, IG 2009a, 'Computer-based Form-generation in Architectural Design – A Critical Review', *International Journal of Architectural Computing*, 7(4), pp.535-553.

Grobman, YJ, Yezioro, A & Capeluto, IG 2009b, 'Non-Linear Architectural Design Process', *International Journal of Architectural Computing*, 8(1), pp.41-53.

Grobman, YJ & Neuman, E 2011. *Performalism: Form and Performance in Digital Architecture* 1st ed., Routledge.

Harris, C 1998, *Handbook of Acoustical Measurements and Noise Control*, 3rd ed, Acoustical Society of America, Woodbury, NY.

Hensel, M & Menges, A 2007, *Morpho-Ecologies: Towards Heterogeneous Space In Architecture Design*, AA Publications.

Hensel, M, Menges, A & Weinstock, M 2006, *Techniques and Technologies in Morphogenetic Design*, Academy Press.

Kolarevic, B 2003, 'Computing the Performative in Architecture', *Proceeding of the eCAADe 21conference,..* Graz, Austria.

Kolarevic, B & Malkawi, A 2005. *Performative Architecture: Beyond Instrumentality*, Routledge.

Lynn, G 1999, *Animate Form* 1st ed.,Princeton Architectural Press, New York.

Malkawi, AM et al. 2003 'Performance-based design evolution: The use of genetic algorithms and CFD', *In Eighth International IBPSA*, IBPSA, Eindhoven, Netherlands, pp. 793-798.

Monks, M, Oh, BM and Dorsey, J 2000, 'Audioptimization: goal-based acoustic design', *Computer Graphics and Applications*, IEEE, 20(3), pp.76-90.

Sasaki, M, Ito, T and Isozaki, A 2007, *Morphogenesis of Flux Structure*, AA Publications, London.

Schmal, PC and Flagge, I 2001, *Digital Real--Blobmeister: first built projects,* 1st ed., Birkhäuser, Basel.

Shea, K 2004, 'Directed Randomness' In P. N. Leach, D. Turnbull, and C. Williams, (eds), *Digital Tectonics*, John Wiley & Sons, p. 96.