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GEOMETRY

Geometry

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Geometry has always held a central role in architecture, and this has had an impact on the way we appreciate and analyse built form, the way we design and construct, the way we develop a discourse about architecture. Design and construction media are evolving and the technological advances affect the reciprocities between form, structure, material, design-to-fabrication processes, and morphogenetic strategies. Geometry is inherent to architectural design and production; however the intersection, crossover and revisiting of traditional as well as computational design methodologies have given rise to an unprecedented geometric freedom, new design and production workflows and are providing an exceptional opportunity for architectural innovation. Natural forms display a great geometric complexity that inspires engineers in their pursuit for innovation, while currently the advancements in computational design have enabled the integration and feedback among disciplines such as physics, biology and mathematics. Inspiration may be found in the geometry of swarm movement, magnetic fields, liquid formations, erosion, plant growth and the underlying logic that produces such forms.

Recent architectural history has showcased innovative paradigms with embedded complexity in terms of form, geometry and structure such as the hyperbolic paraboloids of Felix Candela and the anticlastic surfaces of Frei Otto. In the years to follow the dynamic modelling of lightweight structures was simulated by contemporary numerical tools for design optimization. The ever-growing design explorations with parametric and algorithmic design tools have opened up the design repertoire to non-deterministic design strategies through computational bottom-up processes and performance-oriented geometric articulations that respond to multiple design criteria. As opposed to other approaches to design, where decisions regarding the geometry lie in the starting point of the design process, very often the geometry is developed as a result of simulation, the creative process becomes a negotiation of natural or artificial agents that interact and self-organize giving rise to emergent architectural artefacts.

Geometry relates to both representation as well as materialization; there is an intricate relationship between the tool (analogue or digital) and the form. Tools are mediators between the designer and the object of design. This does not only refer to the design phase where pencils, software, code and physical and digital models are employed to represent the geometry of an object; tools that are used to carve stone, CNC machines or robots have a direct repercussion on the geometry or rather the volumetric qualities of the produced artefact. As Mario Carpo remarks in the *The Alphabet and the Algorithm* (2011) “all tools feed back onto the actions of their users, and digital tools are no exception [...] manufactured objects can easily reveal their software bloodline to educated observers”.

The emerging field of computational geometry relates to both the conceptualization as well as the materialization of architecture, ranging from the microscale, to the macroscale, addressing the design of architectural elements, buildings or concepts. This archiDOCT issue with the aim to trace contemporary research on geometry across different media, and its role within the process of architectural morphogenesis, invited doctoral research essays that focus on any field related to architecture where geometry plays a major role.

It is widely accepted that new technologies have accelerated innovation in architecture. This, as a matter of fact, affects all stages of the design process from ideation to production. The way geometric form relates to architecture can receive several different interpretations. Departing from the modernist principle of “Form Follows Function” that dominated architectural praxis and research for decades, there have been several off-springs and conceptual mutations that associate architectural form generation to forces, rules, software or tools. “*Form Follows Force*”¹ addresses efficient structural morphology through the study of the relation between form and force. Traditional form-finding strategies by Frei Otto at the Institute of Lightweight Structures, as well as contemporary simulations for topological optimization are based on the morphogenetic principle of growth under stress, seeing form as a product of dynamic forces as D’Arcy Thomson² advocated in “*On Growth and Form*”. Contemporary architects strongly rely on observations of natural phenomena, and computational simulations, moving from Otto’s experiments towards artificial intelligence and continuous transformation, often revisiting D’Arcy Thomson’s theories of transformation and his work as a classic for its “exploration of natural geometries in the dynamics of growth and physical processes”³.

The role of nature-inspired algorithms for architectural morphogenesis is among the research agendas of leading architecture schools. Architects are able to simulate phenomena and contextualize emergent forms, discover bottom-up self-organizing structure, assess and optimize a structure based on its topology. Pierluigi Serraino suggested that “*Form Follows Software*”; in his homonymous lecture⁴ at ACADIA 2003, and discussed several case studies where the software used had a direct impact on the design outcome. Current architecture research focusing on digital production would generalize the above statement about software and reformulate it in “*Form Follows Tools*”, referring to both algorithms and digital design media as well as fabrication tools and the reciprocal relationship between processes⁵.

It has become clear that the available digital fabrication equipment as well as the software used has significantly enriched the repertoire of forms, in digitally produced artifacts. This is intelligently reflected in William Mitchell’s famous phrase, that “*architects tend to draw what they*

1. See the article by LI, Qingpeng. *Form Follows Force: A theoretical framework for Structural Morphology*, and Form-Finding research on shell structures. A+BE | Architecture and the Built Environment, n. 2, p. 1-278, feb. 2018. ISSN 2214-7233.

2. D’arcy Thomson in his famous work “*On Growth and Form*” advocated that the shapes of natural forms relate to force fields acting upon them. He exemplified the relationship between structure and geometry in natural organisms and would describe the cancellous structure of the bones as a “diagram of the lines of stress”

3. For a contemporary reinterpretation see Beesley, P., Bonnemaïson, S. (Eds.), 2008. *On Growth and Form: Organic Architecture & Beyond*. Dalhousie Architectural Pr, Halifax.

4. Serriano, P., 2003. *Form follows software*, in: ACADIA, Indianapolis. pp. 185–205.

5. Symeonidou, I., 2018. *Digital Creativity: Embracing New Technologies for Architectural Innovation*, in: D’Uva, D. (Ed.), *Handbook of Research on Form and Morphogenesis in Modern Architectural Contexts*. IGI Global.

6. Mitchell, W.J., 2001. *Roll Over Euclid: How Frank Gehry Designs and Builds*, in: Frank Gehry, Architect. Guggenheim Museum Pubns, New York; London.

can build and build what they can draw”⁶. We could further generalize the above statement to include the notion of making, in the sense that we can construct those artefacts that can be produced with CNC machines and robots, altering strategies for construction, sensing and testing, in an analogue-digital interface, where each design decision can be based on the performance of the actual constructed artefact.

The geometry of contemporary architecture may also relate to the socio-economical context, the political significance of the built form, the natural and the human-made environment. The recent exhibition “*Form Follows Rule*” at Architekturzentrum Wien⁷ shines a spotlight on building regulations and how these shape the geometry of contemporary cities. The list of aphorisms of “*Form Follows*” could be infinite while all of them display a reductionist scope of geometry and its implications, form does not follow a single attribute and the above could be only understood as a trigger for further discussion on the factors that define architectural form. In reality the geometry of an architectural object is subject to a variety of factors which may vary in nature and level of subjectivity and may act symbiotically or in opposition to one another.

Contemporary computational techniques have enabled formal complexity and a great deal of research over the last decade has focused on ways to materialize non-standard architectures. The seamless transfer of information from File to Factory⁸ is gaining momentum while architects realize that the fabrication strategy has a direct impact on the design phase. Especially when freeform designs are to be materialized, the workflow complexity requires specialized software and knowledge to control all phases of the design and fabrication process. There is no universal software that can directly link CAD systems to different types of manufacturing equipment embedding design constraints and optimization strategies⁹, therefore geometrically complex projects are materialized employing ad hoc design solutions and fabrication processes. Both architectural praxis and academia are struggling to fill this knowledge gap within the digital workflow from design to production. Following this market need specialized companies, that provide consulting related to non-standard geometry and fabrication, have come into existence¹⁰.

This emerging new profession that combines the skillset of computer scientists, geometers and mathematicians, is rapidly becoming a global core of applied research and practice, offering consulting services, specialized software and training, either in the form of smaller clusters within bigger studios¹¹ or as University-led research groups that initially conducted scientific research projects within the academia and have evolved into independent consulting services, always maintaining their link to the academia. In the last decade we witnessed the emergence of consulting companies such as Evolute or Design-to-Production, which

7. The exhibition *Form follows Rule* took place at the Architekturzentrum Wien between 23.11.2017–04.04.2018. Information can be found at : <https://www.azw.at/en/articles/form-follows-rule/>

8. The concept of *File To Factory* refers to the seamless transfer of data through CAD-CAM workflows and is described in Oosterhuis, K., Bier, H.H., Aalbers, C., Boer, S., 2004. *File to Factory and Real Time Behavior in ONL-Architecture*, in: Proceedings of the 23rd Annual Conference of ACADIA and the 2004 Conference of the AIA Technology in Architectural Practice Knowledge Community, Cambridge, November 8-14, 2004.

9. Schmiedhofer, H., Reis, M., Rist, F., Suter, G., 2014. *A Framework for Linking Design and Fabrication in Geometrically Complex Architecture*. Presented at the ACADIA 14: Design Agency, Los Angeles.

10. See also Brell-Cokcan, S., Braumann, J., 2010. A new parametric design tool for robot milling, in: Proceedings of the 30th Annual Conference of the Association for Computer Aided Design in Architecture. pp. 357–363.

11. Advanced Geometry Unit (AGU) at Arup initially founded by Cecil Balmond and currently led by Daniel Bosia, the research group at Adams Kara Taylor (AKT), the Specialist Modelling Group (SMG) at Foster and Partners, and Zaha CODE are some of the most prominent praxis-led clusters that work within the interdisciplinary field of computation, geometry and architecture.

specialize in the geometry of complex architectural forms, providing the missing link from ideation to materialization.

The newly founded Center for Geometry and Computational Design (CGCD) at Vienna University of Technology, aims to bridge that knowledge gap, by conducting research in the intersection of geometry and computation, fostering engineers and scientists with the necessary skills to be able to address geometrically complex problems. CGCD aspires to become *“a focal point where geometric theory, initiated by technological needs, is turned into next generation tools for computational design”*¹².

The morphogenetic strategies that extend the formal repertoire to non-deterministic structures, the topological transformations enabled by computational tools and the optimization and rationalization of non-standard structures have all become a hot topic and a great source of inquisitiveness for architects and researchers. The knowledge on that field is building up rapidly and dissemination of research findings is achieved through publications and conferences. Annual or biannual events such as Advances in Architectural Geometry¹³, Smart Geometry¹⁴, Shape to Fabrication¹⁵, and FABRICATE¹⁶, have become platforms for exchanging knowledge among researchers and the industry. Often the discourse relates to the geometry and logistics of complex constructions; geometric optimization and discretization of free-form architecture, the developability of surfaces, the mathematics of foldable and bending structures, among others.

It is a natural consequence of the above that the new generation of architects is much more skilled and curious with regards to digital skills and therefore much more prepared to effectively design and suggest a fabrication method that will be applicable, thus defining the entire workflow from design to production. There is an ever-growing collective knowledge on that topic, freely available to practitioners and students to explore and this is highly reflected in contemporary doctoral research in the field of architecture.

In the quest to showcase different aspects of geometry in architectural creation and research, authors were encouraged to present the reasons why geometry plays a central role in their work and how they explore the relationships between applied geometry, engineering and graphics, research and experimentation in computational design, virtual reality and augmented representation, analogue vs digital fabrication and optimization strategies. The issue includes one good practice example and five essays by doctoral students worldwide.

The good practice example has been provided by Professor Constantin Victor Spyridonidis addresses the theoretical base of architectural

12. Center for Geometry and Computational Design - Mission 2014.

<http://gcd.tuwien.ac.at>
(accessed 1.11.18).

13. <http://www.architectural-geometry.org/>
(accessed 1.11.18).

14. <https://www.smartgeometry.org/>
(accessed 1.11.18).

15. <http://www.shapetofabrication.com/>
(accessed 1.11.18).

16. <http://www.fabricate.org/>
(accessed 1.11.18).

geometry and how this has changed the way we comprehend the built environment based on its representation throughout the history of architecture. Professor Spyridonidis from Aristotle University of Thessaloniki, and the Canadian University of Dubai, affirms that Architecture is addressed to Geometry with entirely different demands in time. As he points out, we could, therefore, suggest there are many versions of Geometry affiliated with architecture, that is to say, many Geometries. His essay examines the role of Geometry in architectural thinking and practice in three major steps of architectural development. The first is the period in which the focal point of architectural thinking is the cosmic and the divine, (from the antiquity till about the 13th Century) where Geometry is that of the Master Builder. The second is the era of humanism where the central preoccupation of Architecture is the human (from the Renaissance to the late 20th Century), and Geometry is that of visual perception. The third is the emerging era of the post-human, where the main focus of Architecture becomes "Gaia," the Planet as an alive ecology that emerges from the synergy between the natural and the artificial, and Geometry is that of data.

The first essay by Mads Brath Jensen is entitled *Robotic Fabrication of Acoustic Geometries* - an explorative and creative design process within an educational context. Mads is a PhD fellow at the Department of Architecture, Design and Media Technology at Aalborg University in Denmark (2017-2020) and has been teaching in the field of computational architecture, parametric design and rapid prototyping technologies on both BSc and MSc level (2008-2017). His essay investigates the relation between creative design processes in the field of architecture and interactive robotic fabrication. It describes and exemplifies a design method for exploring acoustic performance and robotic fabrication of wood panels. Moreover, it studies the cognitive and creative impact of the design method of a 3-week design studio with architectural students, through qualitative observations and a qualitative PCA analysis. The essay describes a computational system that supports non-experts in generating curve-based geometries informed by acoustic analysis and simulation of robotic milling.

The second essay titled *Cellular Design* is authored by Christoph Klemmt who is currently PhD candidate at the Angewandte Vienna and Assistant Professor, University of Cincinnati. Christoph through his research, teaching and praxis as Founding partner of Orproject has been experimenting with self-organizing principles and their applications to a wide variety of projects. The essay casts light into the notion of self-organizing geometries where the designer defines the components of a project or relationships between components giving rise to emerging systems created through bottom-up logic, so that all parts of the material accumulation are developed through local system interactions only. The research employs simulations of intercellular behaviors as an architectural computational design tool. The intercellular logics attempt to simulate natural systems such as the cellular behaviors and growth in organisms and the generated geometries portray various characteristics of architectural relevance, generated through the emergent intercellular behaviors as well as external influences. The essay concludes with test simulations for the design of two case studies: A permanent installation in an office, and the design of a house.

The third essay of this issue tackles the crucial topic of fabricating free-form architecture. The essay entitled *Programming Flat-to-Synclastic Reconfiguration* is authored by Yu-Chou Chiang a PhD Student at Delft University of Technology. This essay is investigating strategies of translating free-form synclastic surfaces to flat pre-programmed reconfigurable mechanisms. The presented bistable mechanisms are produced by creating voids on flat materials in the form of blocks connected by the hinges. The essay shows how the position and the orientation of the hinges allow the blocks to rotate around each other, and then reconfigure from flat to synclastic. The research addresses the geometric constraints that need to be met for the design of such mechanisms and demonstrates

the workflow of identifying the positions of the hinges. The essay concludes with the validation of the developed methods through prototypes of synclastic surfaces.

The fourth essay further elaborates on notions of constructability by examining the behaviour of active bending and the reciprocities between geometry and structure. The essay, titled Novel Bending-active System with Controllable Curvature-stiffness Relation, is authored by Efilena Baseta, who has been a Marie-Curie researcher of the InnoChain ETN network (2016-2018) and PhD candidate at the University of Applied Arts in Vienna. The essay presents a novel bending-active system of low-tech structural elements which increase their stiffness when they reach a predefined curved geometry, relying exclusively on geometrical configurations. The essay presents physical and digital experiments that document the structural performance including the numerical results of load-deflection experiments, as well as the Finite Element Analysis of the joinery detail. The results of the research show change of stiffness of the developed system and its scalability, which renders it an efficient construction method for large-scale curved structures.

The fifth essay of this ArchiDOCT Issue further elaborates on the topic of bending elements, considering the material geometry and introducing an interface of human-machine collaboration. This last essay is titled Using Materially Computed Geometry in a Man-Machine Collaborative Environment and it is authored by Bastian Wibranek PhD candidate and research assistant at the Digital Design Unit at the Faculty of Architecture at TU Darmstadt, where he is currently also teaching in the area of computational design and robotic fabrication. The essay challenges the interweaving of real-world geometry with computational tools for a man-machine collaborative assembly process. It aligns with the current research for robotics in architecture which aims to bridge the gap between digital design and fabrication, but rarely considers manipulation of real-world geometry by human actors. The essay presents a demonstration of the man-machine collaboration, where the designer is engaged with wooden lamellas and a computational tool to build a demonstrator, moving from parametric design tools directly to physical interfaces using real-world geometry, and therefore proposing a stronger participation of human actors within digital fabrication environments.