EN ROUTE TO PERFORMANCE-ORIENTED ARCHITECTURE

The Research Centre for Architecture and Tectonics:
Integrating Architectural Education with Research by
Design along a Practice-oriented Perspective

A B S T R A C T

This article examines the development of the integrative and interdisciplinary approach to research by design in architecture pursued at the Research Centre for Architecture and Tectonics (RCAT). RCAT constitutes the primary research environment of the Institute of Architecture at the Oslo School of Architecture and Design and focuses on an extensive scope of research activities related to architecture and the built environment that are geared towards the development of a comprehensive approach to *performance-oriented architecture*. This involves specific ways of integrating architectural education and research, in particular research by design, to support the development of related knowledge, concepts, methods and frequently also the production of reliable empirical data, engaging real-life design problems and seeking interaction with practice. Advanced computational design underpins a lot of the research, as well as scaled and full-scale construction.

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KEY WORDS

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ADVANCED COMPUTATIONAL DESIGN

‘Performance-based design is really about going back to basics and to first principles, taking into account the experience one has gained over time as well as field and laboratory observations about the non-linear behaviour of elements and components. It is the combination of first principles with experience and observations that is the fundamental potential of the design philosophy. It places the design imperative back in the hands of the designer. And, more importantly, it also places responsibility and accountability back into designer’s hands in a very obvious way. One can no longer hide behind building codes.’¹

INTRODUCTION

The Research Centre for Architecture and Tectonics (RCAT) was launched in 2011 as the primary research environment of the Institute for Architecture at the Oslo School of Architecture and Design (AHO). RCAT focuses on a broad scope of integrative and interdisciplinary research initiatives in architecture that are geared towards the development of a comprehensive approach to *performance-oriented architecture*². The latter entails the understanding that architectures unfold their full capacities by being intensively specific and responsive to the local conditions they are embedded within. (Fig. 01) In so doing RCAT aims at developing intensely *local tectonics*. This involves the initiation and development of key approaches and concepts relative to performance-oriented architecture, advanced design methods – in particular advanced computational design, analysis and visualisation – and scaled and full-scale physical and context-specific construction. These central activities aim at engendering design approaches, concepts, knowledge and frequently also deriving empirical data through exploratory research and design. In order to engage real-life design problems, RCAT collaborates extensively with various segments of practice and industry that pursue similar research undertakings or take a keen interest in it. This paper discusses key developments en route to establishing RCAT and subsequently explicates various research undertakings of the centre.

INTEGRATED RESEARCH AND TEACHING ACTIVITIES PRIOR TO RCAT

Although RCAT was launched in 2011, numerous key activities that are characteristic of RCAT’s research today commenced during the decade prior to its launch.

Figure 01. Top: architecture + ecology: architecture as niche construction and biodiversity provision underpinning urban ecology efforts. Centre: the four domains of performance-oriented architecture: [i] local biological environment, [ii] local physical environment, [iii + iv] spatial and material organization complex. Bottom: architecture + local climate: architecture as heterogeneous environmental modulator.

From 2002 onwards efforts in developing advanced computational design approaches included master-level studios that focused on the utilisation of advanced digital tools, scripting, associative modelling, development of applications and interactive systems, as well as new visualisation technology. For instance, the 2004 Spline studio supervised by Prof. Søren S. Sørensen, Thomas Fagernes and Franco Ghilardi, focused on the design and construction of a skating ramp based on detailed mapping of movement requirements and trajectories, registering and analysing the extreme three-dimensional movements of bowl-skaters. The constructed double-curved ramp was tested by professional skaters in the construction hall of AHO. (Fig. 02)

In 2003 AHO established a formal cooperation with the Institute for Energy Technology (IFE) in Halden (Norway) in research of the use of Virtual Reality in Architecture and Industrial Design. IFE administers the Halden Reactor Project, an international research cooperation in nuclear safety, financed and run as a joint undertaking of national organisations in 19 countries under the auspices of the OECD Nuclear Energy Agency. AHO collaborated with IFE's Visual Interface Technologies division (currently Software Engineering Division) which is part of the Safety Man Technology Organisation that focuses on industrial psychology and behavioural and perception analyses and the Yoshikawa Laboratory at the Kyoto University on the development of technological solutions.³ The first research efforts focused on the use of Virtual Reality in planning for the disabled in the context of an elective course in spring of 2004. The objective of the study was to investigate whether the use of Virtual Reality in planning physical structures and solutions can help to facilitate communication between planners and users during the design phase and enhance the possibility for the disabled to participate in the design process. Research within the field of Augmented Reality (AR) commenced in 2003.⁴ Master students have from the outset been involved in the research and contributed to the development of content, interface and technological solutions through projects with a research by design approach. In a 2005 diploma project master student Halvor Høgset worked in close collaboration with Prof. Dr. Hirotake Ishii from Kyoto University on a large-scale AR installation based on his system with fiducial markers for positioning. Analysing and treating sound-bites by the contemporary composer Arne Nordheim digitally and utilising these to generate controls for shaping, manipulating and animating virtual three-dimensional forms resulted in groups of dynamic AR models reacting to spatialised sound following these in the virtual space, while changing output levels according to distance from the user. The resulting project was designated as one of three proofs of concept at this stage of the research.

The final proof of concept utilizing fiducial markers, a full scale on site visual reconstruction of a historical building, involved master students at several levels. Based on the registrations and analysis by a student in an architectural history studio of how the 13th century church of St. Margaret north of Oslo originally was constructed, it was possible for other students to model a digital replica of the church. Verified by the Norwegian Directorate for Cultural Heritage and as an official part of the National Science Week in 2005, this was presented as a full-scale AR setup at the site with the digital reconstruction superimposed over the existing ruins. (Fig. 03) Users were able to approach the ruins and experience a realistic AR model of the church from different angles as well as viewing the interior through the front entrance. Representatives from the Directorate for Cultural Heritage and the Norwegian Research Council participated in the demonstration and the event was widely covered in the national media. The mounting of fiducial markers for large scale visualisations is cumbersome, requires precision and stability and is vulnerable to the influence from local climate conditions like wind and rain as well as sun glare, so researchers at IFE had been working on implementing algorithms from a differential GPS system in the AR system for positioning. This was tried as an extension of the official programme and proved to give results of equal precision as that achieved with the presented system based on graphical markers.

These research efforts have over the last ten years led to the development of AR systems for visualisation of architectural design that have been introduced to, utilized by (Fig. 04) and further developed by master students. An example is the studio in spring 2007 where the students through exploratory iterations in the design phase of their projects registered user experiences and developed models and guidelines for handling geometry, textures and light to optimize the relationship between the digital information and the physical setting. (Fig. 05) In 2008, as an intrinsic part of his project, the master student Joachim Svella developed an AR application based on the prerequisite that the proposed architectural design should not be realized physically, but experienced as a digital structure on site. This simple to use and affordable system utilized graphical markers, a webcam for recognition and an ordinary laptop for processing and presenting the AR view. The same year Halvor Høgset, now a PhD candidate at the Institute of Architecture, developed a tablet with an AR system in cooperation with Prof. Dr. Hirotake Ishii, allowing users to interact with models intended to be experienced as digital additions to physical reality.

Further efforts were placed on integrating computational design, simulation and fabrication, and exploring full-scale context specific visualisation

Figure 02. Spline Studio 2004 (Supervisors: Prof. Søren S. Sørensen, Lecturer Thomas Fagernes and Lecturer Franco Ghilardi): Construction and testing of skate-ramp.

Figure 03. Proof of Concept 2005 (AHO, IFE, Kyoto Univ.): Illustration of AR reconstruction of the 13th century church of St. Margaret, Oslo.

Figure 04. Digital Architecture Studio 2008 (Supervisors: Prof. Søren S. Sørensen, Lecturer Halvor Høgset, Prof. Marius Watz): AR visualization of scripted computational models.

Figure 05. AR Studio 2007 (Supervisor: Prof. Søren S. Sørensen): Left: parametric computational models of three architectural proposals. Right: renderings and on-site AR visualisations.

by means of augmented reality. (Fig. 06) Based on this research on virtual environments a studio course in spring 2010 led to significant advances in associative design, as well as the development of both a multi-touch interactive interface and a system combining milled terrain models with interactive, projected information and augmented reality. (Fig. 07) A key objective of these studios was to convey research findings and technical innovation within the field of computational design and visualisation to the students and to develop a related research by design approach. The development of programming skills, custom-made software and modified or novel technical solutions was initially not an aim in itself, but resulted from the need of tools to accomplish the desired design results.

Since 2008 interdisciplinary studios, elective courses and workshop sessions brought together architecture and industrial design students. These studios were led by members of the OCEAN Design Research Association and focused on research by design as a mode of inquiry with its own particular modalities. In this context emphasis was placed on the development of (1) auxiliary architectures⁵, in particular complex membrane and cable-net systems, (2) the responsive capacities of materials, such as wood as a porous, heterogeneous and hygroscopic material⁶, (3) design and construction of complex structural brick systems⁷, (4) biomimetics and biological systems analysis, and (5) advanced computational design integrating computer-aided design, computer-aided analysis and augmented reality. Full-scale constructions constituted an essential element of research by design in these studio courses. Other studios courses, although not formally within RCAT, focused on related topics. In 2013 the *Form and Performance* studio supervised by Prof. Dr. Bjørn Sandaker and Prof. Søren S. Sørensen, concentrated on investigating material form and interrelated material properties and capacities, in particular structural, acoustic and light conditions.

Furthermore, from 2008 onwards a number of research-by-design based PhD candidates were encouraged to co-teach studio and elective courses, as well as to direct intensive workshop sessions that relate to their specific PhD-related inquiries. This made it possible to elaborate a vertical system of inquiry that correlates and interlinks master-level education and PhD and post-doc level research systematically.

In preparation of the drafting of the mission of RCAT prior to its inauguration an advisory board was formed in 2011 that consisted of internationally leading experts in practice, education and research in architecture and key

Figure 06. Digital Experimental Architecture Studio 2010 (Supervisors: Prof. Søren S. Sørensen, Lecturer Halvor Høgset): Concept development of interactive AR projects.

Figure 07. Digital Experimental Architecture Studio 2010 (Supervisors: Prof. Søren S. Sørensen, Lecturer Halvor Høgset): Physical terrain model with projected interactive datasets and integrated AR visualisation.

affiliated disciplines. Likewise it was important to carefully map a broad range of interdisciplinary research by design efforts in architectural education in different contexts and locations⁸ in order to formulate the strategic plan for RCAT. This effort is now being extended by mapping the integration of research and design in architectural practices of different sizes and in different locations⁹ with the aim to seek out appropriate areas of shared interests and efforts in order to expand collaboration with practice.

RCAT 2011-13

The first three years of RCAT focused on configuring the specific research approach through (1) further development of an underlying theoretical framework and related research trajectories and methods and in particular initiating the notion of *local tectonics*, (2) creating a related research culture at the institute of architecture, (3) building up a recognised track-record in research and more particular research by design in architecture, (4) initiating national and international collaboration with key partners and (5) preparation of a working environment that can deliver advanced design including advanced computational design in architecture.

*Performance-oriented Architecture*¹⁰ constitutes the theoretical framework and related research approach and trajectories to the centre's scope of activities. Particular focus is placed on combined spatial and material strategies to articulate the built environment, to respond to and modulate local climate and microclimate, to provide for a broad scope of space for locally specific use and habitation and to support local ecosystems. Emphasis is placed both on new designs as well as on supplementing the already existing built environment with *auxiliary architectures* to improve its performative capacities. Key built and unbuilt architectures are revisited from a performance perspective, both in terms of historical¹¹ and more recent projects.¹²

Efforts in establishing research in the use of wood in architecture commenced from 2009 onwards with the Responsive Wood Studio Courses and related seminar courses that focused on a biomimetic approach to wood. (Fig. 08) This effort culminated in a number of noteworthy master thesis projects. In her master thesis Linn Tale Haugen¹³ utilised hygroscopy, the ability of wood to uptake water from the environment: wood is hygrosopic and can therefore absorb moisture from the environment or yield it back, 'thereby attaining a moisture-content which is in equilibrium with the water vapour pressure of the surrounding atmosphere'.¹⁴ Hygroscopy coupled with anisotropy leads to

dimensional variability of the material. In other words, the material can swell or shrink in response to the level of relative humidity of the environment. In a typical laminate consisting of an odd number of layers, the layers are rotated so as to utilize the fibre direction to stabilize the laminate. Likewise, in a laminate with an even number of layers, the fibre direction of the various layers can be utilized to warp the laminate in a controlled way. Specific single or double-curvature can be attained by determining the fibre direction in the different layers and the related directions of swelling and shrinkage in moisturizing and drying the wood. It is then no longer necessary to derive such curved elements by means of machining, such as routing which results in a large amount of off-cuts or sawdust, or, on the other hand, the costly production of moulds.

The Responsive Wood Master Studio 2010, conducted by Michael Hensel and Defne Sunguroğlu Hensel, focused on developing structures and spaces articulated by assemblies of thin wooden strips, a material element that is not usually associated with this capacity. Both self-shaping based on the hygroscopic behaviour of wood and traditional forming of wood by way of jigs were utilized to accomplish complex structural webs made from veneer. Master-students Wing Yi Hui and Lap Ming Wong, for instance, constructed a small pavilion from 0.75 mm thin pine veneer. The dome-shaped pavilion gains its structural capacity from both the global geometry of the assembly, as well as the multiple load-paths of the structural web and the pre-stressing based on the dimensional changes induced by drying of wood. (Fig. 09)

Further efforts in the use of wood in architecture include the Small Buildings Studio in 2011-12 conducted by Prof. Marius Nygaard. Strategic meetings and discussions with the Norwegian Ministry of Agriculture and Forestry, TreFokus, the Norwegian Institute of Wood Technology, the Norwegian University of Life Sciences in Ås and other key organisations commenced in 2011. In 2012 a themed PhD stipend was launched with focus on the performative capacity of wooden surfaces in architecture. Also in 2012 the Bionær Research Grant was awarded to AHO and its collaborating partners to finance the 'Wood-be-better' research project that focuses on the use of wood in architecture in urban contexts.

Design and Construction for Challenging Environments Scarcity and Creativity Studio Courses

Design and Construction for Challenging Environments constitutes a particular research by design effort in developing a comprehensive approach to performance-oriented architecture. The Scarcity and Creativity studio

Figure 08. Responsive Wood Studio 2010 (Supervisors: Prof. Dr. Michael U. Hensel and Defne Sunguroglu Hensel): various full-scale prototypes of wooden structures for the Oslo Architectural Triennial 2010 and the Bergen Wood Festival 2010.

C1 Typical Composites					C2 Material Composites				
	01	02	03	Difference		01	02	03	Difference
3	A	200	200	0	3	A	200	200	0
4	A	150	150	0	4	A	200	200	0
5	A	150	150	0	5	A	200	200	0
2	A	150	150	0	2	A	200	200	0
1	A	150	150	0	1	A	200	200	0
1	A	150	150	0	1	A	200	200	0

C3 Transition Composites 01					C4 Transition Composites 02				
	01	02	03	Difference		01	02	03	Difference
3	A	200	200	0	3	A	200	200	0
4	A	200	200	0	4	A	200	200	0
5	A	200	200	0	5	A	200	200	0
2	A	200	200	0	2	A	200	200	0
1	A	200	200	0	1	A	200	200	0
1	A	200	200	0	1	A	200	200	0

C5 Transition Composites 03					C6 Transition Composites 04				
	01	02	03	Difference		01	02	03	Difference
3	A	200	200	0	3	A	200	200	0
4	A	200	200	0	4	A	200	200	0
5	A	200	200	0	5	A	200	200	0
2	A	200	200	0	2	A	200	200	0
1	A	200	200	0	1	A	200	200	0
1	A	200	200	0	1	A	200	200	0

C7 Transition Composites 05					C8 Transition Composites 06				
	01	02	03	Difference		01	02	03	Difference
3	A	200	200	0	3	A	200	200	0
4	A	200	200	0	4	A	200	200	0
5	A	200	200	0	5	A	200	200	0
2	A	200	200	0	2	A	200	200	0
1	A	200	200	0	1	A	200	200	0
1	A	200	200	0	1	A	200	200	0

Figure 09. Responsive Wood Studio 2010 (Supervisors: Prof. Dr. Michael U. Hensel and Defne Sunguroglu Hensel): Pavilion for the Oslo Architectural Triennial 2010 by master-students Wing Yi Hui and Lap Ming Wong. Top: construction process. Bottom: associative model and related building element dimensions.

series supervised by Prof. Dr. Michael U. Hensel, Prof. Christian Hermansen, University Lecturer Solveig Sandness and Lecturer Joakim Hoen is a key example of integrated teaching and research at master-level education in architecture. In this context the students collectively design, develop, detail and construct projects that have to meet challenging requirements specific to the context of the projects. The SCL33s studio undertook three projects at the Open City in Ritoque Chile: (1) *Walk the Line* is a small temporal accommodation for visiting scholars inspired by Le Corbusier's house for an artisan; (2) *Las Piedras del Cielo* is a small cooking and dining facility; and (3) *Hospederia de las Alas* is a bird observation shelter. (Fig. 10) All projects are set within the Pacific coastal dune landscape of the Open City in Ritoque and need to respond to questions of landscape, scarcity, foundations in sand, considerable wind loads and earthquake impact. These full-scale experimental projects are context-specific and can be analysed over time in relation to the impact of context and provisions for and pattern of use. The studio course continued in spring 2013 with two projects for Nusfjord in Lofoten, Northern Norway (SCL68n). *The Floating Compression Canopy* project consists of a tensegrity system and a landscape inspired furniture system that establishes an outdoor catering area on the main pier of Nusfjord. (Fig. 11) The tensegrity system is made from aluminium compression members and high performance rope used in the naval industry. The *2x2 Bathing Platform* is a landscaped surface that faces the fjord and bridges over a crevice. The project integrates hot tubs and a sauna with a small stepped outdoor seating area that can serve as a small auditorium or bandstand. Both projects are designed to withstand the harsh climate and significant impact of wind and saltwater. In autumn 2013 and spring 2014 the studio focused on the design and construction of an artisan centre in Pumanque, Chile (SCL34s), a village that was largely destroyed during the 2010 earthquake.

Complex Brick Systems: Nested Catenaries

One of the key areas of material systems development at RCAT involves the design of complex structural and multi-performative brick systems and is directly related to the PhD thesis of Research Fellow Defne Sunguroğlu Hensel who leads this line of inquiry. This research commences from the innovative use of form-finding methods to establish the logic of the system under investigation and its optimal structural form. In this work this entails the form-finding method of the hanging chain devised by Antoni Gaudi for the design of the Church of Colònia Güell, yet in this case with interacting chains that influence one another. Phase 1 (Fig. 12 top) commenced in 2011 with a workshop in collaboration with master-mason Øyvind Buset and

Figure 10. Scarcity and Creativity in Latitude 33s Studio 2012 (Supervisors: Prof. Dr. Michael U. Hensel, Prof. Christian Hermansen, University Lecturer Solveig Sandness, Lecturer Joakim Hoen): three projects in the Open City in Ritoque, Chile. Top: *Walk the Line* – minimal accommodation for a visiting scholar. Center: *Las Piedras del Cielo* – cooking and outdoor eating facility; Bottom: *Hospederia de las Alas* – bird observation shelter.

Figure 11. Scarcity and Creativity in Latitude 68n Studio 2012 (Supervisors: Prof. Dr. Michael U. Hensel, Prof. Christian Hermansen, University Lecturer Solveig Sandness, Prof. Guillem Baraut Bover, Lecturer Joakim Hoen): *Flying Compression* tensegrity canopy and landscape furniture. Top: View of the project on the main pier of the harbour of Nustfjord in Lofoten (Northern Norway). Centre: structural analysis. Bottom: associative model and construction information.

Figure 12. Nested Catenaries Research Project 2010- ongoing (Research Fellow Defne Sunguroglu Hensel, Collaborating Engineer Prof. Guillem Baraut Bover, Master-mason Øyvind Buset). Top: Nested Catenaries Phase 1. Centre: Nested Catenaries Phase 2a. Bottom: Nested Catenaries Phase 2b at the Open City in Ritoque, Chile.

master-level students that led to the design and construction of *nested catenary* arches in the construction hall of AHO. The conversations between master craftsmen and architects are frequently highly instructive for both sides. This is in particular of importance in the development of new ways of building as it informs the outcome in an integrative manner and trains both designers and craftsmen equally towards a common goal – an indispensable necessity as far as immediate relevance for practice is concerned. Structural engineer Prof. Guillem Baraut Bover, partner at BOMA Inpasa in Barcelona, joined in phase 2 (Fig. 12 centre), which commenced in spring 2012 with a full-scale test construction of three nested catenary vaults. This phase continued with the construction of an unreinforced masonry shell of interconnected sub-shells in the Open City in Ritoque, Chile, in collaboration with master-mason Øyvind Buset and students from e[ad] in Valparaíso (Fig. 12 bottom). The shell consists of twelve sub-shells, each with synclastic surface geometry and a thickness of 55mm. The span is 7m in both directions, reaching a height of 3.3m. Since its completion the structure has withstood several earthquakes of a magnitude above 6 on the Richter scale. Further planned development stages will focus on the environmental performance capacity of the *Nested Catenary* system and the further rationalisation of the construction process. This project demonstrates an integration of PhD level research by design inquiry with master-level design and construction experiments directed by the respective PhD candidate, while at the same time placing strong emphasis on the integration of engineering and master-craftsmanship in the process. The research was published broadly in architectural and engineering journals and was additionally in various stages reported back to the Norwegian Bricklayers Association and representatives of the brick industry.

In a related workshop series directed by Defne Sunguroğlu Hensel students examined Eladio Dieste's Gaussian Vaults and Free-standing Vaults and modelled these in associative modelling software so as to investigate design solutions that do not rely on a strict axial symmetry for uniformly repeated vaults. This makes it possible to orient the various vault arrays more effectively towards the path of the sun or prevailing wind directions and to organise space in a more versatile manner, while at the same time retaining the specific integrated structural and geometric shell characteristics. The study involves the detailed scale of the brick arrangement to ensure that the modified designs are actually buildable. (Fig. 13)

The Extended Threshold / Auxiliary Architectures

Light structures, such as textile membrane constructions, offer an effective and feasible way to provide auxiliary architectures for existing buildings with

insufficient space for different kinds of use or insufficient climatic performance. This entails that solving existing problems does not necessarily require the demolition of architectures that are deficient, but, instead, the development of means of supplementing the built environment in specific ways. The development of supplementary designs constitutes an interesting field for interdisciplinary collaboration involving architects and industrial designers, as well as structural and environmental engineers and can significantly benefit from collaborative research by design. *The Extended Threshold* studio, supervised by Prof. Dr. Michael U. Hensel, Prof. Søren S. Sørensen, Prof. Guillem Baraut Bover and Lecturer Joakim Hoen focused on this type of research and the related development of complex membrane and cable-net systems, a line of inquiry that commenced at AHO in 2008 with the *Membrane Spaces* studio. Physical form-finding methods and computational modelling and visualisation methods and tools, such as Augmented Reality and Virtual Reality, play a key role in the process of developing auxiliary architectures. In the context of this studio efforts commenced to build custom-made weather stations that feed computational models and analysis with real-time data that serves to acquire a high level of climatic context-specificity of the designs. This has tremendous consequences and extends the scope of inquiry from concept and design development and analysis, to questions of workflow, workspace, tools and techniques, and the way architectural practice will need to be rethought in order to acquire the capacity for cutting edge performance-oriented design for a new and potentially vast market segment. (Fig. 14)

The studio developed projects for two neglected inner urban public spaces in key locations in Oslo. (Fig. 15) The proposed auxiliary or supplementary architectures provide for a rich variety of activities and experiences, in the form of an extended transitional space that is sheltered, yet not fully enclosed in order to maintain maximum public accessibility and usability. Twelve master-level students worked in teams on four distinctive projects that, while sharing principal features, demonstrate nevertheless the broad scope of design that can be accomplished with the shared material system and working methods.

In the preceding Auxiliary Architectures studio students worked with different material approaches that answered a variety of criteria that did not permit the use of lightweight solution. Master students Rikard Jaucis and Joakim Hoen proposed perimeter parking for the site of the American Embassy in Oslo that serves also the purpose of the security perimeter. The parking space is clad on the outer perimeter with double-curved and perforated steel panels that serve to diffuse bomb blast impact while at the same time modulating

Figure 13. Nested C

Figure 14. Eladio Dieste Workshop 2010 (Supervisor: Defne Sunguroğlu Hensel) Top: overall associative model of the Gaussian vault roof of the Julio Herrera & Obes warehouse in Montevideo, Uruguay. Bottom: detailed associative model of a Gaussian vault with all details of the pre-stressed single-brick layer vault.

Figure 15. Extended Threshold Studio 2012 (Supervisors: Prof. Dr. Michael U. Hensel, Prof. Søren S. Sørensen, Prof. Guillem Baraut Bover, lecturer Joakim Hoen). Workspace layout for combined physical and digital form-finding, prototyping and integrating augmented reality visualization.

daylight locally in the area adjacent to the perimeter and giving the project a distinct aesthetic. In order to establish the geometry of the panels structural analysis software was used to form-finding the specific curvature of each panel in tension. (Fig. 16)

Architecture and Ecology

Cornell University's Department of Architecture and RCAT collaborated in organizing two international symposia that focused on the relationship between architecture and ecology. The symposia were financed by the Hans and Roger Strauch Symposium on Sustainable Design endowment and took place at Cornell University in Ithaca, USA. The first symposium took place in February 2012 and focused on the accelerating transformation of the natural environment by humans, which suggested that the built environment was increasingly becoming the context for ecosystems. It may then no longer be possible to consider the built environment as merely asserting negative impact on the natural environment; instead, built and natural environments need to be equally considered as habitats that are designed to provide for biodiversity. It is therefore necessary to shift architectural design toward a non-anthropocentric model that favours the interaction between species and the built environment. On an urban scale, such efforts have taken shape in the interdisciplinary field of urban ecology, yet on a building scale related approaches are sparse and in their infancy. The symposium focused therefore on the question as to how architecture can be developed to set out and instrumentalise specifically related knowledge, concepts and working methods. The second symposium took place in January 2013. During the time between the two symposia related research took place at AHO funded by the strategic budget of RCAT. Prof. Dr. Michael U. Hensel and Senior Lecturer Jeffrey P. Turko (University of Brighton) developed an approach to multi-species provisions in building envelopes and engaging the ground of a project site in order to underpin related larger-scale efforts in the field of Urban Ecology. Prof. Søren S. Sørensen and Prof. Dr. Birger Sevaldson collaborated on the development of a systems-oriented approach to the relation between architecture and ecology and the conceptual development of computational augmented reality approaches and tools that can inform the designer about the ecological makeup of a specific site. (Fig. 17)

GIGA-mapping¹⁵, a central technique in System Oriented Design¹⁶, was used to construct a holistic understanding of the complexity of urban habitats and biodiversity. In order to inform design and scenarios a working augmented reality prototype was developed. The system utilizes hand held devices and camera recognition to register, identify and communicate context-specific

information on species, uploading the geo-tagged information to a crowd-mapping site for further processing and to collectively produce a database of findings. Presented as part of speculative scenarios at Cornell was a prototype of the system with limitations regarding information retrieval and direct uploading to the site. In order to solve these, further research on camera registration and development of species registration, as well as establishing of connected databases is needed.

Currently Prof. Søren S. Sørensen supervises master thesis projects that pursue the technological development of augmented reality tools and their demonstration in specific computationally driven design studies that link architecture and ecology. To exemplify this, the master thesis project of Joachim Sveta addresses the establishing of a national park through developing a distributed system of physical and virtual nodes collectively serving as visitor centres. The grid will consist of differentiated levels of information retrieval, like trail cameras and dedicated weather stations, points of interest with visualization of context-specific information and gateways with real time visualization of animal movements. As a key feature of the assignment a hand-held augmented reality system developed by the student is employed and further developed throughout the process, both as a design tool and as an integral part of the proposed solution.

ADVANCED COMPUTATIONAL DESIGN LAB

Currently RCAT and the Institute of Architecture are in the process of preparing and resourcing the Advanced Computational Design Lab in which master-level students, PhD candidates and post-doc researchers can work together on complex design problems. The aim en route to *local tectonics* is to integrate generative design processes with computer aided design and analysis, real-life data feed based on sensor networks and advanced visualization tools including virtual and augmented reality. Research efforts include the role of augmented reality in visualising structural and environmental behaviour, as well as complex assembly processes. Furthermore sensor networks are utilised to investigate local climate variations in Norway in order to develop related approaches to architectural design and to critique building regulations that are overly homogenising and lead to unsustainable results on a national scale. Digital fabrication will play an important role, however, the laboratory will emphasise ways of materialising that are not necessarily predicated on computer aided manufacturing, as the design output needs to be relevant and applicable in contexts that may not have easy access to computer-aided manufacturing. The

Figure 16. Auxiliary Architectures Studio 2010 (Supervisors: Prof. Dr. Michael U. Hensel, Prof. Guillem Baraut Bover, lecturer Joakim Hoen): *Auxiliary Parking* project master students Rikard Jaucis and Joakim Hoen. Top: Exploded axonometric of the project showing the American Embassy in Oslo (completed 1959) designed by Eero Saarinen, the volume for the perimeter parking and the articulated steel panel skin of the perimeter parking. Centre: detailed light analysis of the light reflection and (self-) shading of the articulated steel skin and the adjacent surfaces. Bottom: computational form-finding, associative model and physical model of the articulated steel panels.

Figure 17. Design for Biodiversity - Architectural Responses to Urban Ecology, Symposium at Cornell University 2013 (Prof. Dr. Birger Sevaldson, Prof. Søren S. Sørensen) Left top: BioTag app on handheld device registering geo-localised information. Left bottom: Visualisation from database. Right: Various screen-views of different functional aspects of the BioTag app.

Figure 18. 3 Houses on the Norwegian West-coast by master student Joakim Hoen (Supervisor: Prof. Dr. Michael U. Hensel). Top: rendered view of one of the site-specific designs. Bottom left: detailed computational terrain models of the three sites; airflow conditions as input into an iterative design process; sectional rapid prototype model of one site-specific design. Bottom right: designs for three different sites that are directly informed by terrain and climate related data.

overall intention is to connect the development of architectural concepts and approaches to computational knowledge and skills and material sensibilities in a tangible way which will require elaborating workflows and interfacing the digital and the physical.

CONCLUSIONS

RCAT has thus far established a broad range of integrated research and educational activities that pursue various aspects of performance-oriented architecture. In order to accomplish a vertically integrated educational model that helps to transfer and proliferate knowledge between different level of architectural education PhD candidates have, wherever possible, been integrated in the master-level education. Similar efforts will commence with post-doc researchers. Now efforts have commenced that aim at linking these efforts in a productive manner with bachelor level education. Moreover, it will be useful to further strengthen the link with practice and the building industries.

In the intersection between the various research efforts begins to emerge an interest into designs that are intensely informed by a range of specific local conditions. The physical articulation of such architectures we refer to as *local tectonics*. (Fig. 18) Current efforts aim to further this research and to examine the potential role of life-data streams from the particular setting of a given project into the design process and to explore the further conceptual ramifications of such an approach en route to performance-oriented architecture. In this process specific data-driven advanced computational design and advanced visualization tools and processes and their integration will continue to play a critical role.

NOTES

- 1 Chris Luebke, "Performance-based Design," in *Architecture in the Digital Age – Design and Manufacturing*, ed. Branko Kolarevic (New York, London: Spon Press, 2003), 284-285.
- 2 See in, Michael Hensel, "Performance-oriented Design as a Framework for Renovating Architectural Practice and Innovating Research by Design," in *Design Innovation for the Built Environment – Research by Design and the Renovation of Practice*, ed. Michael Hensel (London: Routledge, 2012), 121-143., Michael Hensel, "Performance-oriented Design from a Material Perspective: Domains of Agency and the Spatial and Material Organization Complex," in *Performatism – Form and Performance in Digital Architecture*, eds. Grobman, Y.J. and Neuman (London: Routledge, 2012), 43-48. And Michael Hensel, *Performance-oriented Architecture – Rethinking Architectural Design and the Built Environment* (London: AD Wiley, 2013).
- 3 See in, Søren Sørensen, "Augmented Reality for Simulation of Construction and Maintenance in Nuclear Power Plants," in *Toward Innovative Nuclear Safety and Simulation Technology* (China: Harbin Engineering University Press, 2008), 29 - 34. and Søren Sørensen, "Augmented reality for improved communication of construction and maintenance plans in nuclear power plants," *International Journal of Nuclear Safety and Simulation 1 / Vol 1* (2010): 83 - 88.
- 4 Søren Sørensen, "The Development of Augmented Reality as a Tool in Architectural and Urban Design," *Nordic Journal of Architectural Research 4 / Vol. 19* (2006): 25 – 32.

- 5 See Michael Hensel, *Performance-oriented Architecture – Rethinking Architectural Design and the Built Environment* (London: AD Wiley, 2013).
- 6 Hensel, “Performance-oriented Design as a Framework for Renovating Architectural Practice and Innovating Research by Design”, 121-143.
- 7 Defne Sunguroğlu Hensel and Baraut Bover, “Nested Catenaries,” *Journal of the International Association for Shell and Spatial Structures* Vol. 54 (1) (2013): 39-55.
- 8 Michael Hensel, *Performance-oriented Architecture – Rethinking Architectural Design and the Built Environment* (London: AD Wiley, 2013).
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- 11 Michael Hensel, *The Handbook of Sustainable Traditional Architecture* (London: John Wiley & Sons, 2014).
- 12 Michael Hensel and J. Turko, *Grounds and Envelopes – Reshaping Architecture and the Built Environment* (London: Routledge, 2014).
- 13 Shaping Wood – The Material is the Mechanism by Linn Tale Haugen, 2010
- 14 J. M. Dinwoodie, *Timber: Its Nature and Behaviour*. 2nd Edition (London, New York: E&FN Spon, 2000).
- 15 Birger Sevaldson, “GIGA-mapping: Visualization for complexity and systems thinking in design” *MAKING DESIGN MATTER! Proceedings of the Nordes '11: The 4th Nordic Design Research Conference* (Helsinki: School of Art and Design, Aalto University 2011):137-156.
- 16 Birger Sevaldson, “Systems Oriented Design for the Built Environment,” in *Design Innovation for the Built Environment – Research by Design and the Renovation of Practice*, ed. Michael Hensel (Oxon: Routledge, 2012), 107–120.

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NA PUTU KA ARHITEKTURI USMERENOJ KA IZVOĐENJU

Istraživački centar za arhitekturu i tektoniku (*The Research Centre for Architecture and Tectonics*): Integrisanje arhitektonskog obrazovanja sa istraživanjem putem projektovanja zajedno sa praksom usmerenom ka perspektivi

Michael U. Hensel, Søren S. Sørensen

Ovaj članak ispituje razvoj integrativnog i interdisciplinarnog pristupa istraživanju projektovanja u arhitekturi koji se prati i kome se teži na Istraživačkom centru za arhitekturu i tektoniku [RCAT]. RCAT sačinjava primarno istraživačko okruženje Instituta za arhitekturu na Fakultetu za arhitekturu i projektovanje u Oslu i fokusira se na opsežan okvir istraživačkih aktivnosti vezanih za arhitekturu i izgrađeno okruženje koje su usmerene ka razvoju sveobuhvatnog pristupa ka arhitekturi usmerenoj ka izvođenju (performansi). Ovo podrazumeva specifične načine integrisanja arhitektonskog obrazovanja i istraživanja, a posebno istraživanja putem projektovanja, kako bi se podržao razvoj srodnih znanja, koncepta, metoda i često isto tako predočavanja pouzdanih empirijskih podataka, angažovanjem problema projektovanja u stvarnom životu u potrazi za sadejstvom sa praksom. Napredno računarsko projektovanje daje potporu velikom delu istraživanja, kao i realizacijama predstavljenim u razmeri i u punoj veličini.

KLJUČNE REČI: ARHITEKTURA USMERENA KA IZVOĐENJU, INTEGRATIVNO I INTERDISCIPLINARNO ISTRAŽIVANJE PUTEM PROJEKTOVANJA, POMOĆNA ARHITEKTURA, NAPREDNO RAČUNARSKO PROJEKTOVANJE

IN[FORM]ACIJA

Pametna svakodnevna arhitektura

Areti Markopoulou,

with Rodrigo Rubio, Sasa Jokić, Petr Novikov, Tomas Díez Ladera

Kao se tehnologije Informatičke ere i njihov uticaj na arhitekturu menjaju, međusobni odnosi pozivaju na nove ili prilagođene koncepte, u kojima se objekti i gradovi neprimetno prepliću sa digitalnim sadržajem i u kojima je jezik elektronskih veza uvezan sa jezikom fizičkih veza.

Arhitektura ne može biti samo naseljenost i forma, već treba korisnike i sredinu integrisati sa njom.