

Intersecting Knowledge Fields and Integrating Data-Driven Computational Design en Route to Performance-Oriented and Intensely Local Architectures

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Introduction

A continual problem of contemporary architecture is the question of how to negotiate the problem of architecture's increasing global homogenisation and the need to address local specificity. The question is how to unlock the performative capacities of architectures that are informed by their particular setting. In his seminal essay 'Towards a Critical Regionalism: Six Points for an Architecture of Resistance', Kenneth Frampton calls for a strategy that 'is to mediate the impact of universal civilisation with elements derived indirectly from the peculiarities of a particular place'.¹ Regarding the latter, Frampton stated that architecture which derives from this understanding 'may find its governing inspiration in such things as the range and quality of the local light, or in a tectonic derived from a peculiar structural mode, or in the topography of a given site'.² Yet regarding the former, Frampton cautions against an approach that exclusively emphasises optimised technology as this can limit designs 'either to the manipulation of elements predetermined by the imperatives of production, or to a kind of superficial masking' and thus lead to 'on the one hand, a so-called "high-tech" approach predicated exclusively upon production, and, on the other, the provision of a "compensatory façade" to cover up the harsh realities of this universal system'.³ The concerns thus expressed seem equally acute today, and the question arises whether there are theoretical frameworks and design approaches and methods that can be deployed to arrive at the kind of mediation Frampton calls for in the search for

spatially more enriched, and locally more specific, architectures.

One current approach in architecture focuses on a nascent notion of *performance*. As we have discussed elsewhere in detail, most of today's approaches to the question of performance originate from the form and function dialectic that in various guises has dominated architectural discourse since the 1930s and continues to divide architects chiefly into two camps.⁴ The formal approach tends to focus on artistic aspects and invariably centres on the discrete architectural object, whereas the functional emphasis is frequently associated with science and, more specifically, with engineering and optimisation. Protagonists of the former criticise the latter for being too rigid and technocratic, while the latter criticise the former for being too elusive and superficial.

Thus, it seems necessary to seek ways of overcoming the equally artificial and superficial dichotomy between form and function, and to explore performative capacities instead, while avoiding a proclivity for single-minded optimisation. Our approach to this problem and to *Performance-Oriented Architecture*⁵ is rooted in Actor Network Theory.⁶ It ascribes the capacity of agency to non-human domains and elements. This approach focuses on the interrelation and interaction between four domains of agency: (i) the local physical environment, (ii) the local biological environment, and, (iii & iv) the spatial and material organisation

complex that constitutes architecture and the built environment, including the cultural and technological aspects this encompasses. This approach is based on incorporating local conditions as drivers in defining the interaction of architectures with their settings and hence as the key input for generating architectural designs. Our objective is therefore to seek approaches to the question of the 'local' in architecture that are fundamentally performance-oriented and geared towards locally embedded or *non-discrete* architectures, as well as to promote their aggregation into the urban fabric and their articulation by way of locally specific tectonics. This can be accomplished by what we term 'informed non-standard' architectures. These encompass so-called non-standard architectural solutions that are informed from the onset of the design process by data sets pertaining to the specific local conditions and setting of a given architecture.⁷

To achieve this objective necessitates both conceptual and methodological inquiries and approaches. The latter emphasise the integration of advanced computational design aspects and methods, and have led to the implementation of the Advanced Computational Design Laboratory (ACDL) at the Oslo School of Architecture and Design (AHO). In this context, a range of computational data-driven design methods are explored, developed and integrated which facilitate generative design processes fed by a range of context-specific and often real-time data sets. These processes are tested in the specific design and built efforts at Research Center for Architecture and Tectonics (RCAT) – in particular in the context of the Scarcity and Creativity Studio – and serve as both proof of concept and the context for analyses of a wide range of architectural and environmental interactions.⁸

RCAT's and ACDL's approach to *Performance-Oriented Architecture* pursues integrated spatial and material strategies in order to articulate the built environment, to respond to and modulate local

climate and microclimate, to provide for a broad range of spaces for condition-related patterns of use and habitation, and also to integrate with local ecosystems. The understanding that the spatial and material organisation of a given architecture plays the key role in its interaction with its specific setting motivates this approach.⁹ In this context, emphasis is placed both on architectural designs and on supplementing the pre-existing built environment with auxiliary architectures so as to enhance its performative capacities.

On a conceptual and pragmatic level, the attempt to activate the spatial and material organisation of architecture may be addressed by way of *tectonics*, as pursued by Semper and Frampton. Frampton restated the four elements of architecture that Semper had proposed as quintessential historical elements of architecture, defining them thus: (i) earthwork, (ii) the hearth, (iii) framework/roof, and (iv) lightweight enclosing membrane.¹⁰ Moreover, Frampton maintained Semper's classification of dividing 'the building crafts into two fundamental procedures: the *tectonics* of the frame, in which lightweight, linear components are assembled so as to encompass a spatial matrix, and the *stereotomics* of the earthworks, wherein mass and volume are conjointly formed through the repetitious piling of heavy mass elements'.¹¹ Evidently, the proportioning between these procedures and elements was entirely dependent on, and attuned to, local conditions, as both Semper and Frampton pointed out. Frampton articulated and confirmed Semper's understanding as follows:

[A]ccording to climate, custom, and available material the respective roles played by tectonic and stereotomic form vary considerably, so that the primal dwelling passes from a condition in which the earthwork is reduced to point foundations [...] to a situation in which stereotomic walls are extended horizontally to become floors and roofs.¹²

Today's globalisation processes render such differentiation progressively insignificant, given the vastly increasing global mass of reinforced concrete which constitutes a considerable legacy for the future built environment, and the steel frames and glass façades that hold sway in mid- to high-rise urban fabric, in disregard of local conditions. Differences in local climate, for instance, are today by and large balanced by way of technological prostheses added to spatially and materially homogenous and locally indifferent architectures. In order to address this problematic and its intended impact upon the bulk of architecture, it is of interest to link a differentiated understanding of *tectonics* and *stereotomics* informed by local conditions as drivers of difference, with the notion of informed, non-standard architecture that affords a broad, performative, spatial and material repertoire. It is necessary, however, to move the primary emphasis of so-called non-standard architecture away from idiosyncratic formal expression and toward architectures that are intensively embedded in their local environment. This entails a shift away from the design of discrete architectures that stand out from their setting by way of celebrating their superficial difference, towards one that is *non-discrete*. This gives rise to the possibility of articulating an *informed non-standard* architecture that is non-discrete, embedded within its local setting, and produced using local means and resources.

The proposed notion of non-discrete architecture not only entails spatial and material embeddedness, but also expands to include extended environmental conditions and conditioning, as well as locally specific cultural practices of using and appropriating space.¹³ With an understanding of architecture that extends beyond the physical object and towards object-environment interaction across scales and time, the perpetual transformation of the local environment and the underlying dynamics and processes gain importance. The questions that arise from these considerations are (i) how to

methodologically underpin this approach by way of integrated data-driven informed design processes, and (ii) how to select, develop and integrate the various elements that are to make up the methodological framework.

Lines of Inquiry

ACDL's methodological approach to performance-oriented and locally specific architectures integrates recursive processes that combine (i) design generation and analysis based on locally specific design benchmarks with (ii) context-specific life-data input and (iii) materialisation-oriented processes based on locally available resources. These processes are deployed on various scales, ranging from the scale of minute material organisation to the scale of urban fabric.

Integrated generative and analytical computational methods facilitate the production and visualisation of nuanced conditions that develop over time and may underlie complex, multi-faceted design processes. These involve the human subject, the environment, and the spatial and material organisation of architectures as active agents in the production and utilisation of heterogeneous space. In so doing, these methods go beyond merely generating the design of discrete architectural objects and instead consider the wider scope of agency and processes by extending the scale and timeline of consideration beyond the materialisation of an intended design. On the methodological level, this entails an operational matrix of integrated, data-driven methods with various feedbacks. This matrix has multiple entry points relative to design intentions, involved processes, and domains of agency, as well as particular requirements regarding design and scale-related aspects. ACDL currently pursues four lines of inquiry:

1. A first level of architectural and environmental interaction involves the response to, and modulation of, the local physical environment, including the

local climate.¹⁴ Frequently, design processes that engage locally specific climate conditions, such as, for instance, solar impact analyses, employ off-the-shelf analytical software that operates on average conditions and averaged output. Here, one may extend the toolset so that life data can deliver the full range of conditions, including peak conditions. At ACDL, networks of weather stations are configured and utilised in order to analyse local climate variation, which can be dramatic in Norway due to its different climate zones, altitude differences and significant local terrain variations. In a second step, the life data collected from the sensor network is fed into the generative design process and the outcomes are evaluated in relation to the full range of local climate conditions. Wherever possible, we pursue design and built activities that can provide, in context, measurements on the architectural and environmental interaction.¹⁵

2. Materialisation and material performance-oriented design processes are developed along several trajectories at ACDL. The first trajectory concerns the aspect and processes of materialisation. Wherever computer-aided fabrication technologies are locally available, they are incorporated as design-informing criteria and parameters. Wherever this is not the case, locally available craftsmanship delivers driving criteria and parameters. At any rate, locally available material is key to determining context-specific input, together with considerations concerning locally available technology and skills. Secondly, the question of material and materialisation is centrally related to that of environmental performance and the modulation of the local microclimate, and thus feeds back to the question of interaction between architecture and local setting.¹⁶ In so doing, this line of inquiry directly feeds back into line 1.

3. Moving upwards in scale, the aggregation of embedded or non-discrete architectures into the urban fabric is investigated in order to develop

low-rise densification models that are integrated with the local physical and biological environment. This line of inquiry has only just commenced and will for now be omitted from the discussion below.

4. Most types of visualisation in architecture foreground the architectural object. Analysis-oriented visualisation frequently emphasises the interaction between the architectural object(s) and a range of dynamic conditions. However, the exploration of spatial aspects, conditions and dynamics requires a more immersive kind of visualisation. In order to help visualise these elements in the different stages of the design process, and to facilitate communication in interdisciplinary design teams, ACDL develops and extensively deploys augmented and virtual reality visualisation methods. Tools are often developed by the students, frequently based on components that are in the public domain and freely available. Emphasis is placed on the affordability of hardware and software resources for this purpose, so that these are available to all students and researchers.

Each line of inquiry is based on an integration of different methods and tools. Yet from an overarching perspective, the question arises of how to accomplish a conceptual integration across all lines of inquiry. Below, lines 1, 2 and 4 of the inquiry are discussed in terms of their intent and methodological approach, followed by a discussion of questions pertaining to a tangible visualisation of data to support the design team and the design process.

Staging Interaction Through Data-Driven Design Processes

The first line of inquiry focuses on utilising data in the design process that pertains to the local environment, and on coupling this information with use and habitation potential. At RCAT and ACDL, this is done in the context of master-level studios and workshops, as well as in master thesis projects and research in the form of design PhD dissertations.

Frequently, these efforts link the notions of non-standard architecture (where breaking symmetry is essential in responding to specific local conditions) with heterogeneous spatial and environmental conditioning, and employ the building envelope and its articulation and multiplication as a spatial device and environmental modulator. In this context, one set of experiments focused on examining Eladio Dieste's Gaussian vaults and freestanding vaults as exploratory case studies aimed towards knowledge discovery, and as concept and method building, or, alternatively, as proof of concept.¹⁷ The Gaussian vaults were modelled in associative modelling software so as to enable design solutions that no longer rely on a strict axial symmetry for the uniformly repeated vaults that generally characterise brick and masonry vaults. The breaking of symmetry enables a more nuanced orientation of the arrays of geometrically varied vaults towards environmental conditions such as sun path and angle, prevailing wind directions, movement trajectories, and so on, while at the same time retaining the specific integrated structural and geometric shell characteristics.

These experiments entail scales ranging from the extended area that is climatically and programmatically affected by the resulting architecture, down to the detailed brick arrangement, so as to ensure that the modified designs comply with the underlying structural form and principle and are also buildable. Following from this, the next set of experiments combined the first and second line of inquiry: context specific input (in this case, predominantly earthquake impact and ground conditions) and materialisation oriented processes. Organised as either exploratory studies or proof-of-concept in different conditions, a single-brick layer, non-reinforced shell typology entitled 'Nested Catenaries' was developed by Sunguroğlu Hensel, various versions of which were built and analysed.¹⁸ [fig. 1]

The experiments commenced with physical form-finding methods that were progressively

supplemented with computational form-finding methods in an associative modelling environment. The response of the designs to local conditions was initially limited to structural aspects and available materials, such as the Nested Catenaries structure in the Open City in Ritoque, Chile, which needs to withstand severe earthquake and gale force wind impact, and was made out of a low quality local brick and corresponding mortar. In the following steps, the environmental modulation capacity of the system is examined. This research works bottom-up from initial, singular interactions to increasingly complex interdependencies, and from a nested structural system to an integrated nested spatial and environmental system. Each level of inquiry is facilitated by interdisciplinary collaboration that also involves the integration of methods and tools across disciplines.

Another set of experiments combined the first and fourth lines of inquiry: context specific data-driven process – in particular, life data recorded on site – and advanced visualisation as feedback. Light structures, such as textile membrane systems, 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.¹⁹ To tackle this appropriately, local weather conditions need to be measured and fed into the design process. The experiments focused on the design of auxiliary architectures of this kind for a series of public urban spaces in Oslo. Physical form-finding methods and computational associative modelling, local weather data input based on custom-made weather stations, and AR/VR visualisation tools all played a key role in the design process. [fig. 2] Large data sets and complex data interaction are hard to handle for most people, and extended utilisation of data sets in the architectural design process reinforces the need for information to be tangible, hence the use of spatial visualisation. In the context of this studio, efforts commenced to build custom-made weather

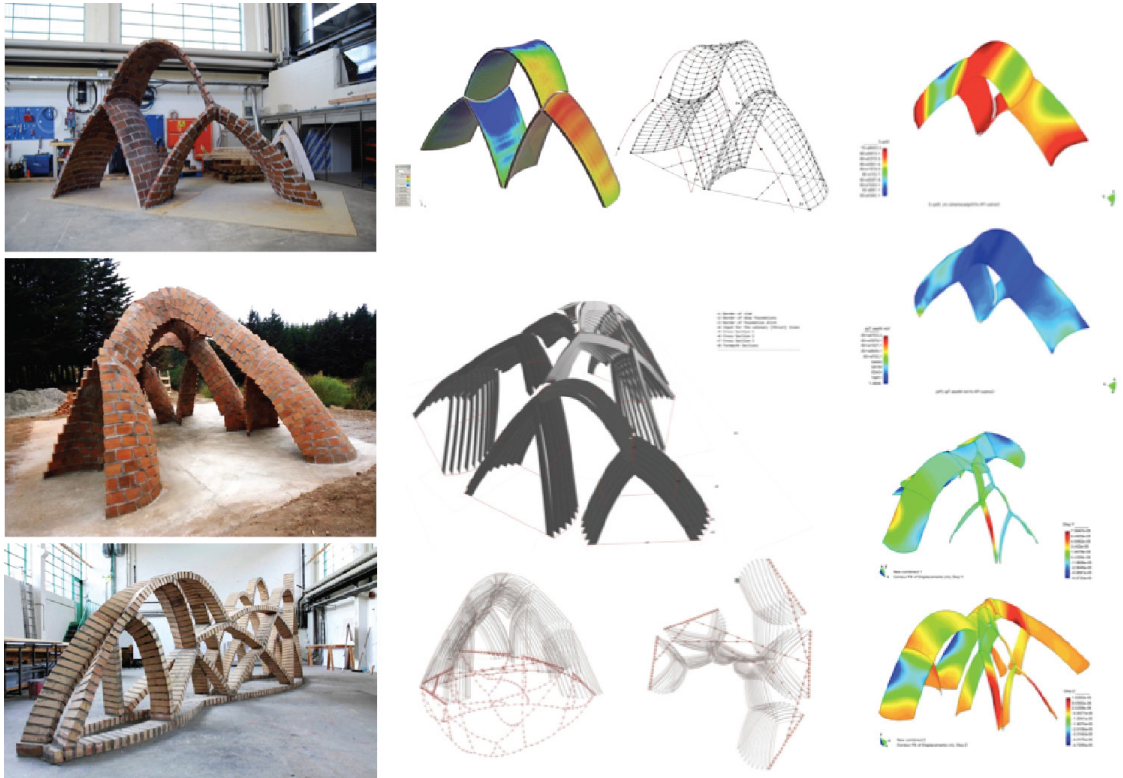


Fig. 1: Design and built projects as Proof of Concept for recursive data-driven computational design processes. Top to bottom: Three stages of development of the Nested Catenaries system as single layer non-reinforced brick arches and shells. © Defne Sunguroğlu Hensel.

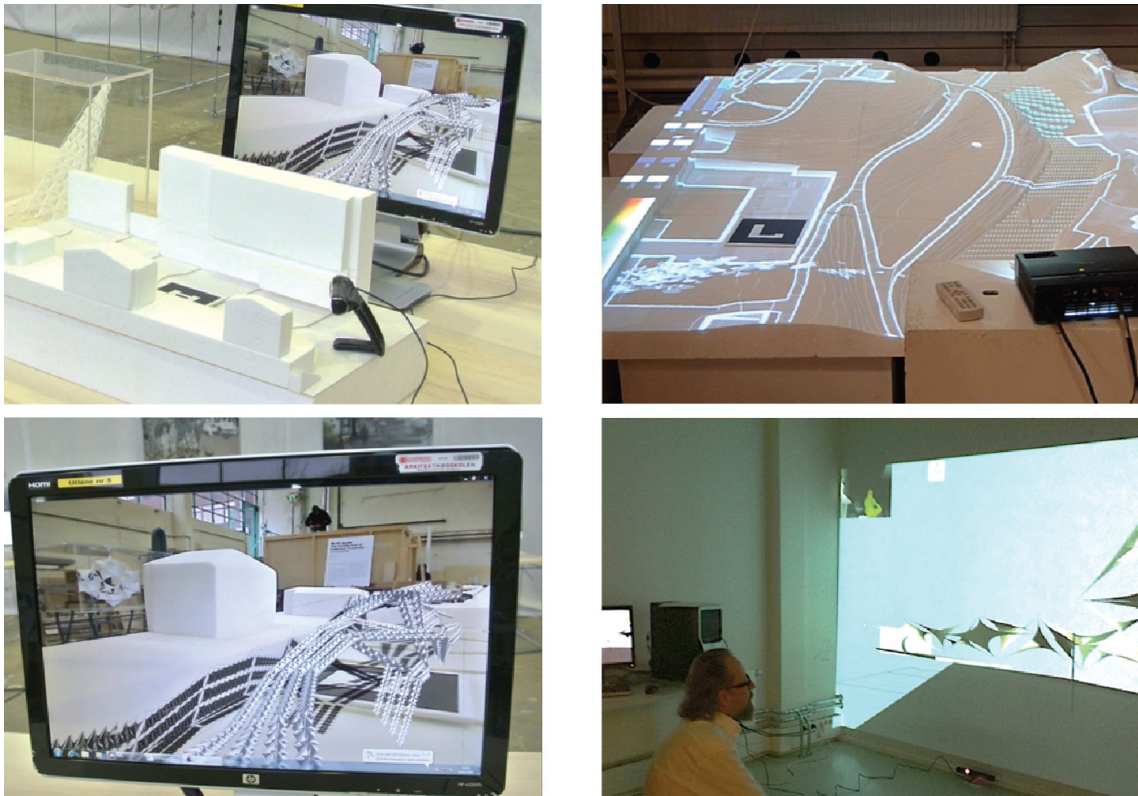


Fig. 2: Various AR and VR visualization set-ups developed and utilized in master-level studios and ACDL. These set-ups are all based on affordable and broadly available technologies. © Advanced Computational Design Laboratory, AHO – Oslo School of Architecture and Design.

stations intended for direct data-feed into computational models and analysis with real-time data, all of which serves to acquire a high level of climatic context-specificity for the designs. This procedure takes care of local variations and peak conditions that occur in specific sites not usually addressed by off-the-shelf software packages that operate on averages. This type of work extends the scope and 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.

In the context of RCAT, various pilot projects have been constructed and analysed in order to deliver empirical data. Locally specific real-time data sets in the design process not only serve to get a much more nuanced understanding of the conditions that precede the design, and thus facilitate detailed analysis prior to implementation, but they can also continue to serve after construction in a manner not unlike post-occupation analysis, although extended beyond the interior or direct vicinity of a given architecture. To acquire this information, entire local environments need to be monitored with respect to context-specific, critical conditions and processes, and progressive and accumulative context transformation. The latter often leads to levels of complexity that require extensive data collection and analysis to enable comprehension.

The third design experiment combined the first, second and fourth lines of inquiry. Frequently, the data required for a particular design process may be already available, but needs to be located and often reformatted so as to drive the design process. The Seaside Second Home project focused on developing design strategies and computational methods for multiple-envelope, non-standard seaside homes for different locations on the west coast of Norway.

[fig. 3] In relation to the overall pursuit of data-driven and informed non-standard architectures, the work constitutes a progressive case in advancing the concept. The specific local terrain articulation and the coastal wind and weather conditions served as environmental input into the design process and informed the articulation of the outer screen-type envelope.

The three sites for the project were strategically selected in order to obtain variation in two critical data sets: one pertaining to the terrain form and the other to the proximity of local weather stations. The specific terrain form of each location was derived from terrain-scans provided by the Norwegian authorities in the form of point clouds that then required translation into a surface model. The three selected sites feature half-metre height line accuracy. From the point clouds a contour model was derived, the accuracy of which also served in the analysis of airflow across the site. The local weather stations delivered the site-specific wind conditions as data input into the generative design process. In this way, the design process was based on data sets that were retrieved from publicly accessible online databanks and converted into a format that can be fed into a generative computational design process.

The design consists of two envelopes: an outer permeable screen that shelters a transitional zone and an inner envelope of variable thickness. The articulation of the outer screen-like envelope primarily concerned the dissipation of horizontal wind loads and the modulation of thermal impact on the inner envelope. It also concerned the deceleration of airflow velocity from the exterior to the transitional space, so as to make it usable during more severe weather conditions. The screen and the outer surface of the inner envelope, constructed according to spatial requirements and environmental performance, articulate the transitional space. The interior is an open space articulated as an extension of the

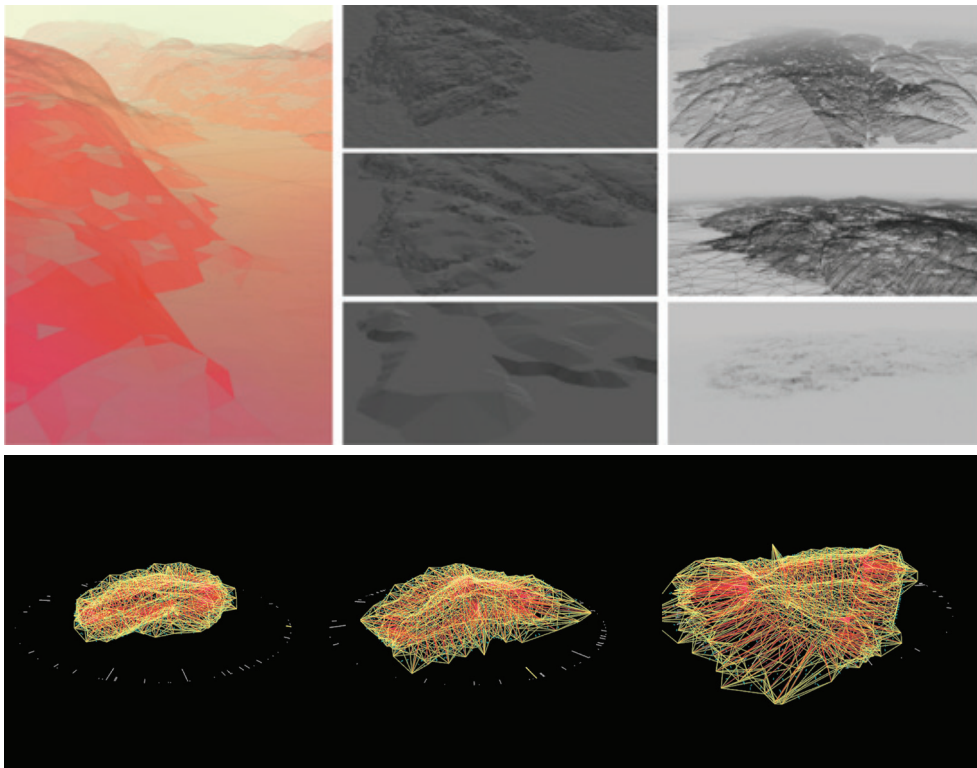


Fig. 3

Fig. 3: Data-driven design for three locally specific houses at the western coast of Norway. Terrain data derived from governmental terrain scans and form-generation based on coastal airflow conditions. Diploma project Joakim Hoen, 2012.

landscape and defined and constrained by sight-lines. The variable thickness of the inner envelope emerges from the different criteria and algorithmic procedures pertaining to the outer and inner surface of the inner envelope. In methodological terms, the designs emerge as an outcome of a series of linked algorithmic procedures fed by data from publicly accessible sources, while employing the relation between environmental performance, programmatic intent, and material preferences as a set of design benchmarks that constrain the possible outcome.

The design of the three Seaside Houses was driven by the same type of integrated data sets, yet with a difference in degree as freestanding objects in surroundings not likely to change dramatically, resulting in variations and adaptation, but also a level of similarity. What characterises all of these design experiments is the pursuit of combined lines of inquiry and the co-development of custom configured design methods and tools, together with concepts and design approaches. Yet the goal is not to derive a universal, integrated toolset. On the contrary, the custom configuration of data-driven design methods and tools, or, in other words, the design of design processes, pertains, in our view, to the same capacity for adaptive expertise that architects acquire and utilise in the design of architectural schemes. The ability to custom configure and integrate case-specific methods and tools is of fundamental importance to the production of a desired outcome with increasingly complex performance demands.

Visualising Complex Data for Design

With the deployment of data-driven design comes the question of how to visualise complex data so as to enable comprehension on the part of the designer and ensure a tangible design process and workflow. This is obviously dependent on the complexity of information contained in each data set, the quantity and interdependence of data sets, and, in

general, the complexity of the design problem. With the increase in this last aspect, it is reasonable to assume that the complexity of the former two will also increase. This, then, implies that the design problem needs to receive some attention.

One promising way of mapping complex systems and relations is based on Sevaldson's research into visual thinking and visual practice methods, in particular, a method he termed *GIGA-mapping*. Sevaldson described GIGA-maps as 'rich multi-layered design artefacts that integrate systems thinking with designing as a way of developing and internalising an understanding of a complex field'.²⁰ As a tool for visualising complex relations in an extensive manner, GIGA-maps can serve the purpose of redrawing system boundaries in a more detailed and expansive manner, or, likewise, provide the visualisation of multiple system boundaries in relation to different sets of criteria and/or different stakeholder configurations. In so doing, they enable the rethinking and redefining of design problems by unfolding an extensive set of interdependencies and relations that hitherto were not considered to this extent.

A second concern relates to the clarity and tangibility of visualisations that contain complex and dynamic data. Here, the typical object-focused visualisations deployed in architecture frequently fall short. Standard representation of spatial and dynamic data on a screen often proves difficult to comprehend. In this case, augmented and virtual reality tools can provide a more immersive spatial visualisation that can be shared among different collaborators during the design process. In the context of RCAT and ACDL, projects often involve experimentation with, and co-development of, AR and VR applications to support data-driven design processes. In the next section we will briefly describe two examples.

The *ARive Mobile BioTag* research project focused on the potential roles of architects and designers in the development of urban ecologies on an architectural scale. It operated from the correlation between the built, the farmed and the gardened in relation to the emergence and systemic complexity of natural systems. The proposed methodological approach combined Systems Oriented Design and *Giga-mapping* with advanced computational systems and visualisation, and purpose-made local weather station networks. Crowd mapping and augmented reality were used as the key technologies for registering, understanding, planning and increasing awareness, and for enabling the maintenance of urban habitats.

The implementation of augmented reality was made possible due to a decade of research on AR in architectural design directed by Sørensen at AHO.^{21,22} Augmented reality serves this context primarily as a visualisation technology that can be described as a computer-assisted, real-time blending of digital, geo-localised, contextual information with the user-view of the actual physical surroundings. In short, AR enables the visualisation of data sets and simulations in context, not removed from, but in direct relation to, the environment. Although AR also encompasses aural information such as spatialised sound, current applications focus mostly on the visualisation of pre-modelled 3D structures, animated simulations, graphics, video and text. The actual simulation in most AR systems today is the relation between the digital structure or information and the physical surroundings in which AR is applied. Our objective is to develop systems where AR is a more integral part of the computational process.

The AR software entitled BioTag is intended to be proprietary and not reliant or based on open source code. The BioTag application includes real-time communication with databases on species and their

interrelation, on-line access to official records and development plans, and full integration of the crowd mapping solution for geo-tagging and uploading registered information. In addition to utilising camera-recognition for recognising animal tracks, leaves and plant diseases, and retrieving information on these from databases and presenting them to the user, the system is also designed to utilise on-board GPS and gyro to position retrieved spatial information, such as proposed building volumes that can be viewed on the screen of the handheld device. In this way, the AR application enables access to sets of interrelated ecological information not normally readily available to architects, while visualising data in a tangible manner.

In the case of the ARive Østmarka National Park project – a cross between a Nature- Visitor Centre and a National Park Centre – this approach was further developed. Numerous commercial and freely distributed AR applications are available today, but none of these adequately offers users the possibility of easy adaptation to their own needs. Often, programming skills are required, or the use of pre-created software with little or no real-time control. However, architects and designers need to be able to implement their own models with the possibility of manipulating these in real-time.

An integral part of the project was therefore to further develop major parts of the AR solution from the ARive mobile BioTag project to the level of a fully functioning application for Android OS. The resulting software was divided into two parts: (i) a design and process tool for architects and designers, and (ii) a dedicated application constituting the information retrieval/presenting and user interface for the distributed National Park Visitor Centre. In addition, the weather station network described above was further developed so as to feed real-time data to the AR system. [fig. 4] Prerequisites for both were ease of use, robustness, minimal response time, stable

and high frame-rate, and high quality rendering. In addition, ARive Mobile enabled the import of models with materials, custom lighting and real-time shadows, tools for airflow and sunlight analysis. This, then, allows architects and designers to use AR in various ways, including in the design process for the evaluation of design iterations in context, as an analytical tool to visualise data, for defining and integrating external environmental data and presenting projects, and for defining the environmental conditions of the specific local setting.

The second iteration of ARive is as a working prototype for use in the park itself, with the software and framework constituting the visitor centre. Instead of adhering to a traditional procedure and strategy of designing, the centre could be incrementally developed as a distributed system of autonomous physical and virtual nodes connected as an integrated unity that together constitutes a National Park Visitor Centre, independent of traditional built structures. The benefits are the geographic distribution of processes, resource-sharing independent of large central resources, fault tolerance and scalability.

The intermittent realisations that arise from this line of inquiry, which concerns the visualisation of complex conditions and processes for designers and for use in the design process, are threefold: (i) AR and VR visualisation is able to provide an immersive environment in which design can focus on performative aspects based on interactions between architecture and the environment (see, for instance, the auxiliary architectural research); (ii) such visualisations can underlie and facilitate interdisciplinary research and design efforts by making conditions tangible and comprehensible that are not normally within the knowledge domain of architects, and (iii) the user can be involved either in the design process, or, alternatively, have a visually extended information source that transcends the physical object and its interaction with the environment.

Conclusion and Outlook on Further Developments

This paper has discussed various stages of developing data-driven computational design processes en route to performance-oriented, intensely local architectures and tectonics. Each of the examples discussed displays a different range of integrated methods. What emerges from the various above-mentioned projects is an understanding that the emphasis of design is gradually encompassing a range of specific local conditions and processes across spatial and time scales. These conditions need to be defined on a case-by-case basis in relation to the specific aspects of the design brief and setting, with each case being extensively mapped out in its complex relations. Giga-mapping may serve as one method for doing so.

This approach also involves a number of dynamic processes, each with its own duration, velocity and timeline. What this points to is the need for data-driven generative processes to also be configured case-specifically. For this to be possible it is necessary to consider the specifically relevant sets of data, their interrelations, the process setup, the definition and delimitation of the specific search space, criteria and methods for analysis and evaluation, aspects of comprehensibility and thus visualisation, and, ultimately, the workflow and workspace. These factors, in turn, indicate the need to reconsider the training of designers so that they are able to work in this manner. For this reason, lines of inquiry are specifically defined and combined for each design problem and local setting.

While integration into a unified toolset may seem tempting, different modes and combinations of integrated methods and tools need to be pursued. And while generalisation is always to some extent necessary, it may soon get in the way of catering for a local specificity of conditions that are not only different in degree but also in kind. This relates in obvious ways to the level of complexity an architect

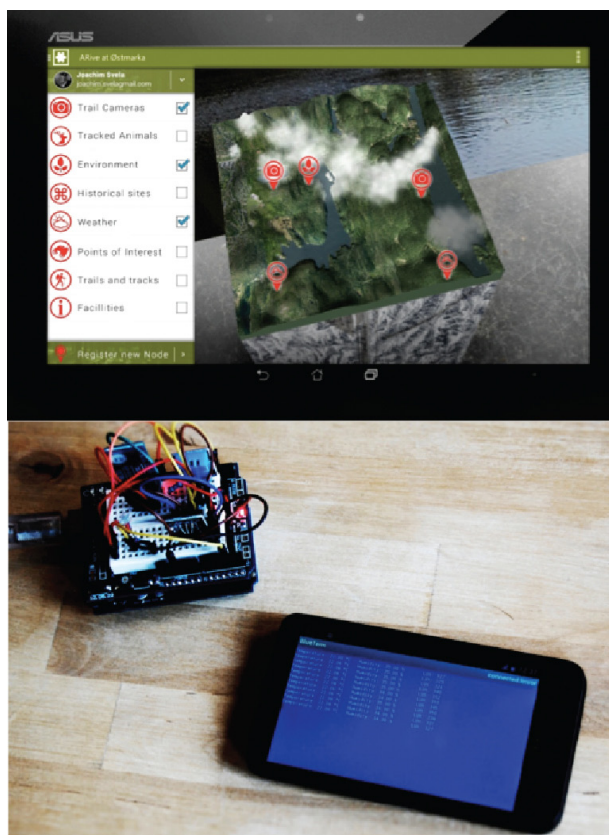


Fig. 4: Custom-made weather station and the ARive Østmarka National Park Project application which utilises and visualises life data transmitted by the weather stations and other sources. Diploma project Joachim Sveta, 2013.
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wishes to encompass and address in the design work. Therefore, it seems useful to foreground the capacity for adaptive expertise not only in relation to architectural design in general but, more specifically, to the integration of related objectives, concepts and methods vis-à-vis data-driven generative design.

Obviously, prescriptive, finite approaches run counter to the intent of deriving an intensely locally specific performative architecture, unless the objective is to arrive at yet another style or 'ism' in architecture. If, however, the intent were to engender the design of a broad range of architecture and environmental interactions, it would seem clear that no single architectural expression or style could result from this. What is critical at this stage is to acknowledge the associated conceptual challenges and potentials in relation to defining an intensely local architecture based on locally specific data sets. One immense challenge is generated by conditions involving complex interactions that are mutually inhibiting or accelerating, that spiral upwards in scale, that exceed critical thresholds, and, as a result, lead to dramatic changes. This should alert us to the fact that the results of data-driven generative design processes should be evaluated with a necessary degree of caution.

At this stage we have (i) studied the performative capacity of materials and material systems in interaction with specific environmental conditions that were informed by, and checked against, material experiments; (ii) explored architectural designs derived from their interaction with environmental condition inputs, whether finite or enduring, and, wherever possible, tested these in full-scale constructions; (iii) commenced the conceptualisation of niche creation and design for biodiversity in architecture, an approach that will require more complex data-driven processes, and (iv) commenced utilising AR and VR tools during the design process as a way of making complex aspects and interactions more

comprehensible, and enabling a more spatial experience of these interactions.

These different elements within our research seem compatible and integrable if a specific design problem requires this integration. Generally, however, it is of vital importance to map, define and integrate conceptual and methodological objectives for a given design problem or project in its own right. To instil this capacity for tapping into the considerable potential of using data-driven computational design processes is our aim.

Notes

1. Kenneth Frampton, 'Towards a Critical Regionalism: Six Points for an Architecture of Resistance', in *The Anti-Aesthetic: Essays on Postmodern Culture*, ed. by H. Foster (Port Townsend: Bay Press, 1983), p. 21.
2. Ibid.
3. Ibid. p. 17.
4. For a detailed discussion see Michael Hensel, *Performance-Oriented Architecture – Rethinking Architectural Design and the Built Environment* (London: AD Wiley, 2013).
5. Ibid.
6. ANT – Actor Network Theory as formulated by Michel Callon, Bruno Latour, Johan Law, et al.
7. In 2003-04 the Centre Pompidou in Paris mounted an exhibition titled *Non-standard Architectures*. It foregrounded the capacity of computer-aided design in the production and industrialisation of architecture with the aim of showcasing 'the generalisation of singularity, within a new order: the non-standard'. This was demonstrated by built and unbuilt projects by some of the key proponents of digital methods and techniques since the early 1990s, such as Asymptote, deCOI, Greg Lynn FORM, KOL/MAC Studio, NOX, Objectile, Kas Oosterhuis, R&Sie and UN Studio. In 2014, the authors of this paper curated an exhibition entitled *Informed Non-Standard*, which examined the integration of both computational design approaches and tools. The aim was to synthesise form, performance,

- use and making, and, in an increasing number of cases, the re-emerging role of local, context-specific conditions that can underlie and inform these integrated computational design approaches. The exhibition took place from 28 April to 22 May at Galleri AHO in Oslo, Norway.
8. Scarcity and Creativity Studio <www.scls.no> [accessed 03 July 2014]
 9. For a detailed elaboration of the role of the spatial and material organisation of ground and envelopes as vital performative elements, see Michael Hensel and Jeffrey P. Turko, *Grounds and Envelopes: Reshaping Architecture and the Built Environment* (London: Routledge, 2015).
 10. Kenneth Frampton, *Studies in Tectonic Culture: The Poetics of Construction in Nineteenth and Twentieth Century Architecture* (Cambridge MA: MIT Press, 1996), p. 5.
 11. Ibid. p. 5.
 12. Ibid. p. 6.
 13. This may, for instance, entail considerations as to how locally specific practices such as 'the right to roam' (in Scandinavia the 'all man's right') – a series of customary practices that govern public access to uncultivated and/or privately owned land – can underpin approaches to settlement organisation and ground articulation. Such an approach can help to embed otherwise overly generalised settlement patterns and building types into locally specific settings and practices.
 14. For a discussion of architecture and environment interaction, both in terms of design generation and intended output, see Michael Hensel 'Material Systems and Environmental Feedback Dynamics', in *Emergent Technologies and Design: A Biological Paradigm for Architecture* (London: Routledge, 2010) pp. 63-81.
 15. This is frequently done in the Scarcity and Creativity Studio (www.scls.no) at the Oslo School of Architecture and Design.
 16. For a detailed account of related experiments see *Morpho-Ecologies*, ed. by Michael Hensel and Achim Menges (London: AA Publications, 2006), and *Form Follows Performance: Zur Wechselwirkung von Material, Struktur, Umwelt*, ed. by Michael Hensel and Achim Menges, Arch+188 (2008).
 17. Michael Hensel 'Confronting the Crisis of Architectural Education', in *Nordic Journal of Architecture*, 1, 2 (2012), pp. 85-9.
 18. Defne Sunguroğlu Hensel and Guillem Baraut Bover, 'Nested Catenaries', in *Journal of the International Association for Shell and Spatial Structures*, 54,1 (2013), pp. 39-55.
 19. For a detailed discussion see Michael Hensel, *Performance-Oriented Architecture: Rethinking Architectural Design and the Built Environment* (London: AD Wiley, 2013).
 20. Birger Sevaldson, 'GIGA-Mapping: Visualization for Complexity and Systems Thinking in Design', Nordic Design Research Conferences, Helsinki, 2011 <<http://ocs.sfu.ca/nordes/index.php/nordes/2011/paper/view/409/256> [accessed 02 October 2011]
 21. Søren S. Sørensen, 'The Development of Augmented Reality as a Tool in Architectural and Urban Design', in *Nordic Journal of Architectural Research*, Vol. 19, No. 4 (Blindern: SINTEF Academic Press, 2006), pp. 25-32.
 22. Commencing from the visualisation of radiation fields in nuclear reactors, AHO has been part of a multi-disciplinary research effort with the Institute of Energy Technology, IFE, Norway, and the University of Kyoto, Japan. Through this collaboration, new AR systems were developed with a main emphasis on full-scale visualisation of architectural structures on site.
 23. Søren S. Sørensen, 'Augmented Reality for Improved Communication of Construction and Maintenance Plans in Nuclear Power Plants', in *Progress of Nuclear Safety for Symbiosis and Sustainability, Advanced Digital Instrumentation in Control and Information Systems for Nuclear Power Plants*, ed. by Hidekazu Yoshikawa and Zhijian Zhang, (Osaka: Springer, 2014), pp. 269-74.

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