Complex Modelling

Questioning the Infrastructures of Information Modelling

Mette Ramsgaard Thomsen
Royal Danish Academy of Fine Arts, Copenhagen, Denmark

Introduction

We are finding ourselves in a time of rethinking our material practices. As research into design computation matures, its fundamental links to fabrication are challenging industrialised paradigms of building construction. With origins in the many explorations of mass customisation and material investigation, our practice is entering a new era in which architects become the designers of materials as well as artefacts. The interest in designing directly for fabrication has transcended the scales of materialisation moving from the fabrication of individualised building elements to the direct production and specification of the materials themselves. This extension of the digital design chain integrating the design of not only material systems but also the composition of their components is now an overarching paradigm informing research and finding its way into practice.
In this paradigm materials are no longer standardised to a measure of global uniformity, but instead locally tuned and optimised. This thinking is linked to interdisciplinary efforts in the broader fields of engineering and material science that are rethinking how we materialise our world. We are living in a time of extreme material inventiveness and are surrounded by highly engineered materials. The 20th century has brought with it an era of synthetic and engineered materials from the artificial silk of nylon stockings to high modulus polymers, ceramic composites to Nano-materials.¹ Now, architecture and building culture is entering this way of thinking. The link between design and direct material manufacture and the ability to programme advanced steering mechanisms has allowed architects to prototype material systems that grade intensity or structure in response to design intent, optimising material usage and employing inherent material performances. In architecture, the ability to use materials in smarter and less intense manners are fundamental building blocks for the conception of lighter building culture; a culture in which lighter means less material, less transportation and altogether a lighter impact on our environments.

This paper discusses the modelling paradigms needed to engage with this new material practices. If traditional architectural drafting has successfully transitioned into parametric design paradigm such as Building Information Modelling (BIM) and other more bespoke computational design practices, the question remains how we transform these systems to engage the

profoundly inter-disciplinary and inter-scalar design environment of the extended digital chain. When we design across the scales of the building system, the element and the material, we encounter multiple scales of engagement, all of which has its own discipline specific modelling paradigms. This paper questions how these models can be integrated so as to enable strategic exchange between them, and what underlying infrastructures we need to develop in order to work successfully with these concepts. The claim is that these new practices necessitate new modelling practices that fundamentally exceeds the boundaries of existing modelling paradigms and that it is this ground research question that is the core enquiry of our time.

Constraints in current modelling practices

At present, the development of digital design tools in architecture is structured around large-scale industry led efforts that have sought to standardise information and develop shared protocols between inter-disciplinary partners. However, core efforts such as BIM have proved inadequate in tackling the high degrees of complexity of current building practice while at the same time not being able to support the needs for flexible, intuitive and communicable design processes. Practice is aware of these embedded limitations of current modelling practice and the industry development has therefore been paralleled with a series of profession-led research and development efforts creating bespoke modelling methods allowing complex design solutions and creating links to fabrication. The practice of architects building their own information tools, encoding their models and engaging directly with model interfacing is therefore an embedded part of existing practice. However, this effort is project-led, practice-specific and rarely shared.

As building culture enters a rethinking of its material practices, we need to future-proof our representations. Rather than building common standards and libraries for known practices, we need to develop the fundamental infrastructures for yet unknown practices. This position fundamentally challenges some of the cornerstones of present modelling paradigms.

The ideal of the unified model: The ambition to integrate all design phases and practices has proven difficult as different practices use different kinds of tools to analyse and represent knowledge. BIM models are breaking their own modelling frameworks in terms of pure scale becoming bigger,
wider and deeper in the sense that they encompass more information from more disciplines (bigger), they include more phases or design (wider) and they expand into new scales of design concern (deeper). This is creating a bottle-neck that is impeding innovation and creativity in architectural design practice. Instead of integrating information into one containing model, we need to build networked models that pass information between discreet part models that are dedicated to particular tasks and can be continuously tuned and changed.

**A persistence of hierarchy:** Building practice is traditionally organised hierarchically as a sequence of subsystems each with their own scale of engagement and team of specialised professions. This division persists within modern design practice and is mirrored by legislative according of responsibility within the design chain. However, this understanding of design as a progression through the scales limits the potential for design innovation as it excludes our ability to understand how the small scales - material or detail - can affect large scales – environment or structure. To support a real implementation of feedback in the design chain we need to develop mechanisms for multi-phased and multi-scalar feedback in which cyclical interdependencies can be investigated and assessed.

**The expectation of known design parameters:** Design is a process of discovery. Unknown opportunities and limitation appear through the collective
investment into the design phase. However, current information modelling necessitates a priori understanding of key design parameters. When new parameters appear, design models break and either need reprogramming or become messy hacks. A central premise for the future of the information model is therefore that it engenders open topologies by which adaptive parametrisation can take place so that we can build models in which parameters can appear or conversely dissipate into constants without breaking the design logic.

**Geometry as information interface:** Finally, we need to reconsider our reliance on geometry as a prime interface for information. Simulations and generative design processes include numerical modelling occurring across discreet time steps though which solutions emerge. We therefore need to expand our perception of modelling as something that occurs in time and through event. Furthermore, as we start implementing more complex n-dimensional data analysis algorithms such as k-means clustering, the description of three-dimensional extension becomes a limitation in our means of visualisation of a design space. Finally, the expansion of digital design chain, making material design part of architectural design, also includes the encounter of new discipline- and scale-specific models that do not fit with geometric representation. Where building culture is used to other means of description such as numeric tables for processes such as cost estimation or stress strain graphs, these are understood as secondary to the actual

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3D model. As new modelling methods mature, we need to understand the inherent heterogeneity of the networked model while retaining the creative and intuitive properties of our own methods.

Researching Complex Modelling

In CITA, the enquiry into how these modelling paradigms are changing have shaped the last five years of research. Currently this is framed by the research project Complex Modelling, a framing project supported by the Danish Sapere Aude Advanced Research Programme. Here, we are exploring future modelling paradigms and how methods from parallel disciplines including engineering and computer science can broaden our practices and transfer central concepts and tools. With special focus on systems that integrate material performance, engage high degrees of interdependency and allow the emergence of design agency and feedback between the multiple scales of the structure, the element and material, our aim is to prototype future methods for information modelling. The project builds on CITA’s central investigation into material performance. Here, material performance is understood as a core resource for design innovation being closely tied to material optimisation. Positioning feedback as a central concern cascading through all scales of engagement, the project asks how dynamic modes of organisation can introduce new logics into the design of architectural information models.

Where an initial interest in Complex Modelling lay with the abstraction of the high dimensionality of complex solution spaces and the construction of methods by which to strategically steer these, it has become clear that the challenge is not how to design in n-dimensions but rather how to understand and capture interdependency. In Complex Modelling interdependency occurs at multiple levels – between material systems, between scales of material manipulation, between modes representation and modes analysis and simulation and between explicit design strategies and those that are generative and optimised. As such, each project engenders its own distinct landscape of networked models. Where concepts and tools are ported across projects, each project finds their own particular way of orchestrating these into cohesive wholes.
The following goes through some of the central enquiries of Complex Modelling. These are exemplified through brief project presentations. Complex Modelling follows an experimental design led method in which a series of linked research projects as well as ‘sketch probes’ act as material experiments. The emphasis on the design and implementation allows the project to engage directly with the investigated techniques and technologies moving along the digital chain from design and analysis to specification and fabrication. This integrated approach positions the research inquiries within a network of interconnected expertise and practice. The results, the design probes and the demonstrators generate shared empirical data that can be further tested, analysed and evaluated. The projects are therefore to be seen more as vehicles by which the research enquiry can be undertaken than as independent research goals. The discussion presented here therefore moves across multiple projects exposing the methods by which different concepts are investigated.

Integrating Simulation

CITA’s central interest in material performance has led to a fundamental exploration into integrating simulation. The emergence of the shared digital design platform has brought with it an opening up of traditional disciplinary boundaries and a merging of core modelling concepts. The ability to interface complex analysis tools for the simulation of force and flow, such as Finite Element (FE) analysis that discretise complex problems into finite numbers of interrelated nodes to compute their force-relations, is influencing the thinking of structural design enabling the realisation of buildings with higher degree of formal freedom and structural complexity.7

In CITA, our interest lies especially with the integration of simulation into the early design phases. By allowing simulation to not only be employed as a concluding evaluation of an already mature design, but also a tool for exploration and form finding, simulation becomes part of a larger set of dynamic modelling tools for exploring and creating design possibilities. This has meant a particular interest in light-weight spring-based simulation tools including first Nucleus8 and later Kangaroo but also self-scripted physics engines.9 In our extensive exploration of active bending10 and highly interdependent material systems,11 we examine light-weight simulation as a means of understanding and formalising material behaviour, calibrating the bending of timber lamellas or GFRP rods and calculating its interaction with


interconnected tensile members. In these investigations, simulation is not seen in isolation, but rather as intrinsically correlated. Light-weight simulations are both tested against and testing more solid FE simulations allowing for continual feedback between early stage design exploration and later stage design refinement. Similarly, simulations are not limited to material or structural simulation, but incorporated into a larger framework of simulation particular to each individual project. These have included light simulation, computational fluid dynamics or agent-based simulations by which design performance, structural performance and material assembly are negotiated.

This practice of conceiving the information model as comprising multiple design integrated simulations only intensifies as we work in a multi scalar design space. Here, scale specific simulations at the scale of the structure, the element and the material are interfaced, passing information between individual part models. As such, simulation is not singular, but instead recurrent and distributed across the landscape networked model.

Simulations introduce important concepts to design modelling. Occurring in time and through event, simulation necessitate time steps thus making us understand design as the incremental movement towards solutions in difference to the explicit shaping of absolute form. This new temporality of our computational design space is exploded and discontinuous. Rather,
discreet events can be called, occur in parallel or enact in isolation triggering new design decisions.

3.2 Adaptive Parametrisation and Open Topologies

A second focus in Complex Modelling is the exploration of methods for adaptive parametrisation in the information model. To preserve design control, parametric models necessarily operate with a reduced number of design parameters thereby reducing the complexity of the model. Where this
is practical, it also limits our way of understanding the potential of design synthesis and leads to an inherently reductive design process.

The field of computational design is currently engaged in a push to build new models of for understanding and capturing the emergent effects of high-order parametric design. Here, new tools are being prototyped for understanding multi objective optimisation allowing architects to navigate the design space along the Pareto-front and “…giving feedback on the best trade-offs that were found so far.” These new tools support existing concepts for understanding design as ‘optioneering’ or ‘versioning,’ in which the singular design object, is seen as part of a larger space of possibility, that were introduced already in early digital design processes. However, they often entail a fundamental fixing of the underlying topology onto which variation is processed.

To retain the flexibility of this new design space, we need to embed the possibility for change of the topology of the design model. Open topologies, in which the dependencies between parameters are emergent and open to change during the design process, allow an inherent flexibility in design by enabling the activation of new - or the neglecting of obsolete – parameters. We need to build methods by which these can be steered and controlled so that we can move beyond random mutation and into much more deliberate progressions.

Image 7  Lacewall
Mette Ramsgaard Thomsen, Martin Tamke, Anders Holden Deleuran, Mateusz Zwierszycki, Yuliya Sinke, CITA 2018.

In CITA recent work is exploring these concepts through dynamic modelling tools including growth algorithms and machine learning tools. Growth algorithms introduce interesting ways of understanding the model as actively evolving through the design process. This firstly establishes a temporal dimension to the design model but also allow us to think of topologies with changing body plans.\textsuperscript{15}

This enquiry into open and adaptive modelling strategies has led to an interest in machine learning. Here, generative and evolutionary design strategies are coupled with tools for emergent classification. In sketch projects such as “Learning to be a vault” we have explore, supervised as well as unsupervised learning methods for clustering large scale design spaces into formal classification systems, guided both by the designer and allowed to emerge from a design model’s underlying data structure.\textsuperscript{16}

Topological thinking has furthermore led to an interest in graph modelling as a means to represent and manage the underlying interconnectivity of design parameters, and in new projects we are exploring neural networks methods such as NEAT (NeuroEvolution of Augmenting Topologies)\textsuperscript{17} by which to create evolutionary processes that can change and optimise design topologies.

These processes present alternative strategies to the embedded reductionism of parametric modelling. Here, models exist in multiples – in thousands of models – that are spawned by the generative system to then be analysed.
by the learning system. Models are no longer singular end points but belong to processes of expansion, increasing in number and in complexity by each time step of evolution. The designer becomes part of a design cycle in which classification, querying and management of data sets become new design concepts.

Multi scale modelling

In CITA, the interest in these new modelling paradigms is how they impact on the way we work with material systems. Where the above outlines strategies for developing model landscapes composed of multiple dynamic and interacting part models operating across different design phases and multiple scales, the question becomes how inter-model communication is facilitated. The aim is feedback. Rather than reducing the digital chain to adhere to a traditional perception of design as a one-way process of refinement consecutively encountering ever smaller scales, our interest is in supporting inter scale relationships, in which design at the small scale is linked to design at the large scale.

This is explored through concepts for multi scale modelling. Multi scale modelling is interesting because of its broad interdisciplinary application in problems that aim to analyse and represent large scale problems with high...
degrees of complexity and where it becomes intractable to model the problem within one unified model. Multi scale modelling presents methods for coupling and interfacing models so that meta scale models can be informed and parametrised through lower scale models but also conversely parse information back down through the design chain thus profiting from both the macroscopic models as well as the accuracy of the microscopic models.  

In CITA we employ multi scale modelling methods using both nested strategies in which lower scale models neatly reference the uniform subdivision of a larger scale model as well as more tactical strategies in local variation in the scale subdivisions correlate to areas of higher degrees of complexity. In these strategies, the mesh becomes a shared interface allowing the translation of information between different scales of design engagement. The mesh is no longer only a geometric descriptor but instead a dynamically changing infrastructure coarsening or refining so as to keep information at the right resolution level.

Conclusion

Complex Modelling is one out the many projects across our community to explore these paradigms. Although perhaps unique in its focus on the underlying infrastructure of advanced digital modelling, it is part of larger
push to expand and evolve our modelling practices. Our community is maturing. With large scale research projects such as the Digital Fabrication NCCR at ETH, the Biological Design and Integrative Structures at University of Stuttgart and Innochain at CITA and across six European institutions, our field is contributing with real solutions for future building culture.

However, we need to be much more conscious of the research contribution that the evolution of our modelling methods is presenting. Where projects tend to foreground the particular structural, material or performative advancement it is investigating, the new modes of information modelling developed to do so are equally important. Our field is criticised for being speculative or overly interested in formal aspects of design, both by more conventional practice and by our neighbouring disciplines. However, I believe that we need to think of these multiple experiments as the prototyping of methodologies. As such, we are embedded into a culture of ground research exploration, which will profoundly change the modalities of architectural representation. This is important because, as all architects know, the means of representation are our means of conception and enaction.

Furthermore, it is a field in which we are contributing quite singularly. Where design computation is fundamentally interdisciplinary, and core research engagements are achieved because of the broad disciplinary project teams, then the evolution of the design model tends to be in the hands of the architects. Perhaps this is because geometric representation traditionally is in the hands of the architect or because it supports the architect’s role of orchestrating collaboration. Despite the actual methods being highly interdisciplinary coming from computer science, engineering, material science or biology, then it is architects that are standing for these transfers of knowledge.

We are transforming our practice and presenting a new consideration of design as something inherently dynamic, interconnected and incongruous. Here, complexity is not an extravagance but rather the probing of a future to come.

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Mette Ramsgaard Thomsen is Professor of Digital Technologies and leads CITA (Centre for Information Technology and Architecture) at the Royal Danish Academy of Fine Arts, Schools of Architecture, Design and Conservation. During the last 15 years her focus has been on the profound changes that digital technologies instigate in the way architecture is thought, designed and built. In projects such as Complex Modelling and Innochain she is exploring the infrastructures of computational modelling, including open topologies and adaptive parametrization. She is pursuing design-led research at the interface of computational design and material thinking. Recent projects focus on advanced modelling concepts examining how machine learning and big data can become solutions for highly interdependent materials systems.

In 2016 she was awarded the Elite Research Prize for outstanding researchers under 45 years of international excellence by the Danish Ministry for Higher Education and Science. In 2016 CITA was awarded the “Innovative Academic Program Award of Excellence” by the prime conference within the field, ACADIA (Association for Computer Aided Design in Architecture).