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Design exploration supported by digital tool ecologies

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ABSTRACT

Designers take advantage of tool ecologies in order to find the most purposeful way of connecting often distinct processes that inform morphological design and associated building performance feedback. The ability to set up logical connections of design parameters across different digital applications becomes ever more relevant in a time where the proliferation of computational tools has led to a fundamental transformation in architectural education. Morphological exploration and form-finding get increasingly enriched by environmental performance feedback. This paper points out a major step forward in software interoperability and the alignment of digital design applications, allowing users to engage with morphological form-finding enriched by real-time physical building performance feedback. The key innovation presented here relates to tools available to designers who neither possess in-depth programming skills, nor need to rely on custom-developed scripts in order to advance their concepts. A recent architectural design studio serves as a testbed to interrogate the level of convergence among tools for morphological design and performance optimization.

1. Introduction

Applying high-end digital technology in architectural design allows users to engage with iterative processes that prioritise form-finding over form-making [1]. Utilising such tools and associated techniques allows designers to challenge traditional means of architectural composition. They help them to study complex system behaviour and include energy simulation and performance analysis as an integral component of the design process [2,3]. Traditionally emerging as discrete forms of inquiry, geometry formulation and building performance optimization is on a path of increasing convergence. The impact of computational tools on creative design exploration across architecture and engineering has been a constant point of research and discussion since such tools have become available to designers more than four decades ago. Various modes of interaction between design morphology and environmental performance feedback were investigated, both in terms of an academic context [4–7] as well as their practical applications [8,9]. These previous efforts either report on custom frameworks that encompass a number of design and performance-analysis capabilities in order to offer operators a bespoke solution, or they highlight the opportunities for connecting existing infrastructures via intelligent data-schemers that allow for an integration of information across otherwise distinct processes or even software platforms. The research presented here reports on an alternative development: the increasing proliferation of an interoperable tool-environment with progressing expansion facilitated by user input via open-source plugins. Findings presented here highlight the level of novelty introduced via such an environment and its effect on the ability of tool-users to work seamlessly across a range of design and analysis applications. The research points towards unprecedented opportunities for design exploration both by operators in practice, as well as educators in academic (design studio) setting.

2. Research methodology

The approach taken to gather the evidence presented here is based on three complementary activities: Firstly an introduction to tools and tool ecologies based on a literature review surrounding digital design applications, parametric design and building performance optimization. Secondly a reflection on tool-use by students, established by the author over a period of ten plus years of teaching design studios, and thirdly a focused report on outcomes from the 'Over and Up' studio conducted at the author's home institution. It contains an in-depth comparative account of approaches taken by students in addressing tool ecologies for design and optimization.

3. Tools and tool ecologies

Designers typically use a great number of digital tools to set up geometry, visualize and test design options, engage with performance feedback, and realize their ideas via digital making and production [10]. Some tools allow for integration of design data with other applications whereas others only offer users to carry out specific tasks in isolation. The latter process results in a disruption of the information-chain when operators have to redefine geometry for each separate

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application. Furthermore, tools that are neither interoperable, nor allow to translate design parameters across different streams of investigation, do not offer designers the opportunity to interrogate their project's geometry across different fields of inquiry (such as structural or environmental performance). As stated by Mitchell [11] there exists a constant interplay between tool user and tool maker with one pushing the other for novel solutions. Architects and engineers respond to the challenges presented above in a number of ways. Available literature suggests that a well-organised and interoperable tool-ecology can foster the design process to the point where collaborative ecologies become sociocultural systems, consisting of persons, activities, tools, and ideas that are mutually constructive [12]. Investigations into interoperability across tools and the establishment of tool ecologies have become a primary concern both in practice as well as in architectural education. Not only do these investigations consider the technical aspect of linking information from different sources, they also consider the resulting changes to the epistemological context and the cognitive abilities of architects and their engineering colleagues.

Parametric Design has become a game-changer in design education and in practice [13]. For early-stage design exploration parametric design approaches have proven to be a useful ally to allow designers to optioneer design variations connected to building performance feedback. Over the past 10 years, the author has researched this area in great depth in order to investigate the transformative character inherent to the introduction of digital applications to the design process [14–16]. It is suggested here that the key association to this transformation that occurred during this period is: 'convergence'.

Convergence in the field has not only taken place as a cross-over from geometric modelling to performance simulation and analysis tools [17], but also (and more recently) via interoperability from early exploratory design towards object-oriented design documentation and delivery tools [18].

Upon analysis of commonly available software applications in the early 2000s, a segregation between geometric modelling and visualization tools for architects on one hand, and highly targeted engineering tools for simulation and analysis on the other hand becomes apparent. Back then, architects would predominantly focus on formal geometrical explorations and topological manipulations in addition to (or in combination with) photo-realistic rendering of design geometry [19]. The tools available for designers to do so were 3DsMax™, Maya™, Lightwave™, formZ™, or Rhinoceros™, to name just a few. The increased use of parametric modelling techniques in the mid-2000s (and referring tools such as Dassault's CATIA™ or Bentley's Generative Components™) initially focused on formal geometrical explorations as well, but this time the rule-based approach to modelling allowed for more controlled manipulation of geometry based on declared parameters. Still, the use of parametric tools was only slowly interfaced with tools for building performance simulation and analysis.

The author previously reported on a number of different approaches: a plugin connecting parametric approaches in CATIA™ with Finite Element Analysis (FEA) in NASTRAN/FEMAP™ and evolutionary structural optimization ESO [20]. Most of the data linkages related to that research had to be custom-developed. They were one-way streets that did not allow for a fluid two-directional exchange of information between parametric geometry optimization and structural analysis feedback. Based on this research, the author helped to develop a framework (DesignLink) to connect a number of engineering analysis tools to parametric model generation and modulation (Reference withheld for reviewing purposes). In that context, the optioneering approach was discussed in greater depth: it complements technological advance in connecting distinct software applications with a novel model of collaboration in a multidisciplinary setting. Both previous examples highlight the need to overcome the often cumbersome nature of information transfer between design and engineering applications, and in particular the desire of users to be able to map design parameters across different applications during design exploration.

The need for establishing closer links between design and analysis did not solemnly stem from designer's aim to engage more with building performance feedback. Since the mid-2000s, there has been a pull from a number of authorities around the world to include considerations of environmental sustainability in the way buildings are conceived. LEED or BREAM ratings in the US and the UK, and Green Star ratings in Australia (to name just a few). Academic institutions responded to these challenges by adding environmental performance assessment courses to their architectural design curricula. Not only has it become relevant for architecture students to understand the impact of environmental sustainability in order to respond to policies and pre-defined performance targets, they also need to understand how to incorporate environmental aspects into their design-thinking within the design studio. Architects can and should not be expected to engage with physical building performance in the way engineers do. They nevertheless benefit from immediate feedback about certain performance trends and they benefit from a better understanding of the underlying principles behind physical building performance. Increasing their knowledge in this field allows architects to engage in more informed conversations with their engineering colleagues.

The author has taught and reported on design classes where the combined use of parametric modelling and environmental analysis was a fundamental element of the programme [21]. These efforts drew on previous research including work on the environmental assessment tool ECOTECT™ [22]. As much as ECOTECT™ offered architecture students an intuitive introduction to a range of environmental analysis functions for evaluating heat-gain, solar and acoustic performance and others, a bi-directional and sustained connection between morphology optimization and physical building performance was missing. Links from ECOTECT™ to the parametric modelling tools such as Generative Components™ or McNeal's Grasshopper™ plugin for Rhinoceros™ only occurred one-directionally. Physical (environmental) properties associated to geometric elements needed to be re-mapped to those elements once geometry was altered. Associations between parametrically alterable building components and their environmental performance got lost once parameters were changed.

4. Increasing the convergence between design and building performance feedback

Despite the challenges that lined the path of the integration between parametric modelling and building performance optimization, the author reports on major progress that has been achieved in this area of investigation over the past decade. In the period from 2005–2015 the use of associative modelling and performance analysis has become the mainstream in the architectural design studio. At the same time, architecture students increasingly connect their associative models with an ever growing number of plugins for building performance evaluation. The international SmartGeometry group has been one of the most active proponents of this development, but other groups and events have similarly contributed to the increased uptake of parametric techniques connected to environmental building analysis in practice and academia [23]. In reflection on the progress within this period a number of key developments stand out:

- **The erosion of the boundaries between tools for architectural design and engineering analysis.** There is an ever growing notion of these tools being applied by either group.
- **Greater interoperability between geometric modelling for design morphology and performance simulation/analysis functions with less dependence on export to third party tools for calculations/appropriations of data.**
- **Increased user-friendliness of interfaces that appeal to a more visually driven design approach by architects.** Visual scripting combined with graphic user interfaces and a 3D model environment appeals to architects more than text-based data entry. Better

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