A Case Study in Teaching Design Space Construction Methods

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Abstract

To make building design decisions with confidence, multidisciplinary Architecture, Engineering, and Construction teams need to systematically define alternatives, analyze tradeoffs, and communicate rationale. However, formal design space construction and exploration methods are not typically taught in schools or used in practice. Academia and industry must discover together how best to adopt and apply these methods in AEC contexts. The Design Space Construction project is a multidisciplinary community of industry, research and teaching organized around a platform of curricula, tools, challenges, case-studies and data for understanding and improving design space construction and exploration methods. This paper describes collaborative tool and curricula development, an industry challenge, resulting student project responses, and data from a graduate course in Building Information Modeling.

1 Introduction: The need to develop, test, and teach design space construction methods

The environmental, social, and economic impacts of built environments are becoming clear and measurable. Pedagogy and practice must prioritize methods that enable systemic thinking and performance assessment. In order to confidently solve performance-based design problems, design teams need to construct and explore design spaces. Design Spaces are models that help teams systematically generate alternatives, analyze their lifecycle impacts, and make and communicate a decision (Clevenger et al, 2012). AEC design problems are wicked, thus skilled and multidisciplinary design teams need to be able to iteratively construct and explore design spaces.

However, the AEC industry – which includes students, faculty, researchers, clients, designers, engineers, builders, suppliers, managers, and others – lacks a formal language and procedural rigor to construct and explore design spaces. In order to leverage the clear communication, design automation, and knowledge reuse that the formality of design spaces afford, the industry needs to reimagine the way it approaches design problems. We need new tools, curricula, case studies and data that inform us how to best construct and explore design spaces on each project.

This paper comes from an ongoing, holistic effort to develop a community of practice and research focused on the continuous improvement of design space construction and exploration methods. First, the Design Space Construction (DSC) project is introduced. Next, we present the tools and curriculum developed for a Building Information

Modeling (BIM) class of 14 students to teach the students the basics of how to construct and explore design spaces. We then introduce an industry design challenge, student projects, and data collected. Finally we discuss the ongoing DSC project and next steps.

2 Design Space Construction

Today's tools, processes, and curricula do not formalize design spaces. We need to change the tools we build, the way we teach students, the way we design and learn from our processes and buildings. The development and implementation of new processes in practice requires a collaborative, ethnographic-action research approach (Hartmann et al., 2009). Adopting emerging design space construction and exploration methods requires multidisciplinary industry expertise, performance-based design software, curricula, research, and students to engage an iterative project of constructing, exploring, and improving the methods.

The Design Space Construction Project (found at http://DesignSpaceConstruction.org) is a community of research-minded professionals and practice-minded researchers who are interested in advancing the understanding, development, and application of design space construction methods. This project aspires to be: Vertically integrated – involving undergraduates through post-docs, and interns through principals; Horizontally integrated connecting AEC and other disciplines; Research informed – researchers develop and test new methods on real and challenging problems; Practice-informed – based in real world project data and tools, industry providing those problems and domain expertise in solving them; and Iterative – involving continuous knowledge building and testing process that is generational and exponential in impact. Figure 1 diagrams an overview of the project.

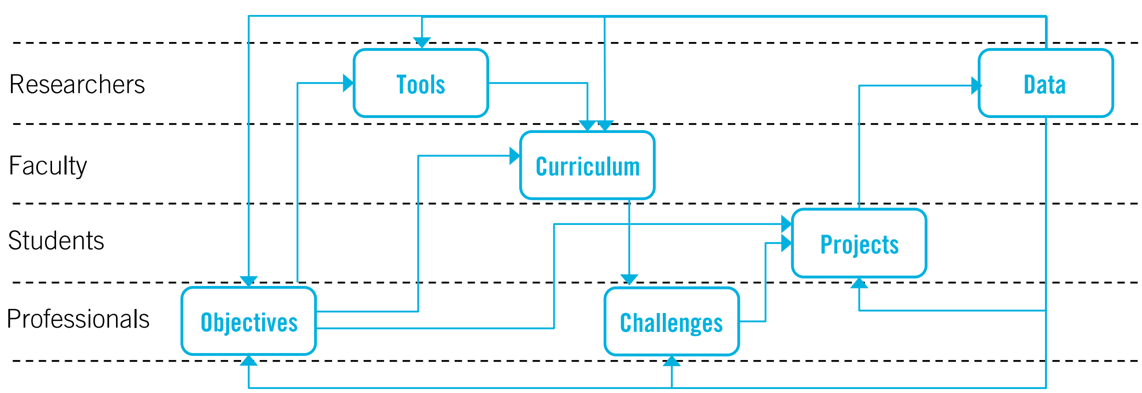

Figure 1. DSC is a community improving design space exploration methods.

The DSC project seeks to integrate these concepts and actors into an iterative process of constructing objectives, tools, curricula, design challenges, projects, and data to improve our knowledge about which tools and curricula work best on which challenges, and why. The diagram suggests that different actors focus on the refinement of different aspects of a design knowledge system. In reality, people do not always fit neatly into one swim-lane and can participate and take leadership in the curation of all information.

This paper describes a case study implementation of a DSC curriculum taught to students in a BIM course in the Masters and Ph.D. of Architecture program at a major US university. The paper describes the curriculum developed, the industry challenge proposed, the student projects, and the resulting data.

3 Curricula & Tools

The curriculum and workflow, conceived using a BIM authoring tool – Autodesk Revit and a visual programming platform - Dynamo, guided students through four steps to construct and report a basic design space.

Parametric Building Form – The first step gives students a sample file containing a parametric Building Generator as a template, and shows them how to create a parametric model, propagate variations, and get simple metrics. Two simple metrics (building volume and floor area) are calculated. Student use this template to improve the model to generate more complex geometries. Figure 2 illustrates the Dynamo graph student's used to generate, analyze, and document building forms in Revit.

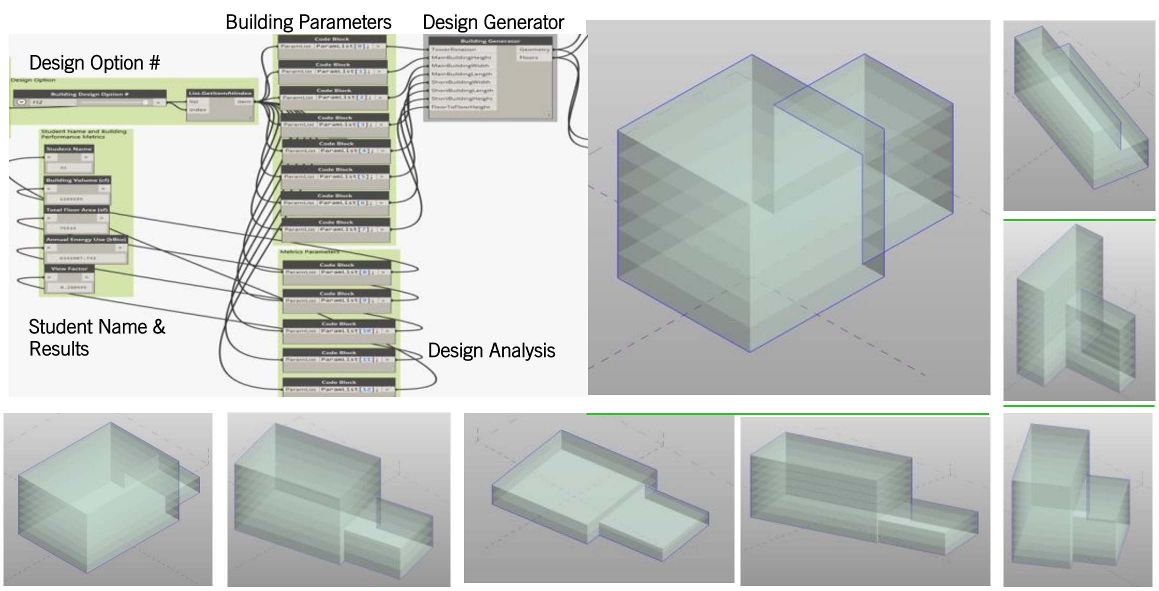

Figure 2. Dynamo (top left) and student generated buildings in Revit (right, below).

Building Analysis – The next step adds two metrics (Annual Energy and Floor Area). The energy analysis uses a linear regression model that is generated for specific weather data and building properties, including building geometry characteristics such as building floor area, wall area, and window area along with some additional combined geometry-related factors to predict building annual energy use (Rahmani Asl, et al., 2016). Students explored parameters to achieve total floor area of 100,000 sf (or as close as possible) and minimal Annual Energy Use. Floor Area and Window Area determined View Factor.

Decision Making - This next step combines the previous components with the Dynamo's

Optimo (Rahmani Asl et al., 2015) package to optimize the building performance and write the values to a data sheet for visualization. Optimo uses Genetic Algorithm (GA) for optimization. Students were taught the optimization workflow as an iterative process. Their programs generated multiple buildings, evaluate them, sorted them by performance metrics (i.e. floor area and energy use), and produced the next generations of buildings using GA's crossover and mutation methods. Figure 3 illustrates how students ran Optimo to automatically optimize the conceptual building design for the building floor area and energy objectives given in the Building Analysis task. The horizontal axis shows the deviation from floor area (calculated as the absolute value of actual floor area subtracting target floor area of 100,000 sf). The vertical axis shows the energy use. The graph shows students solutions that optimize energy use for progressively smaller building footprints, one of several optimizations the students are able to run.

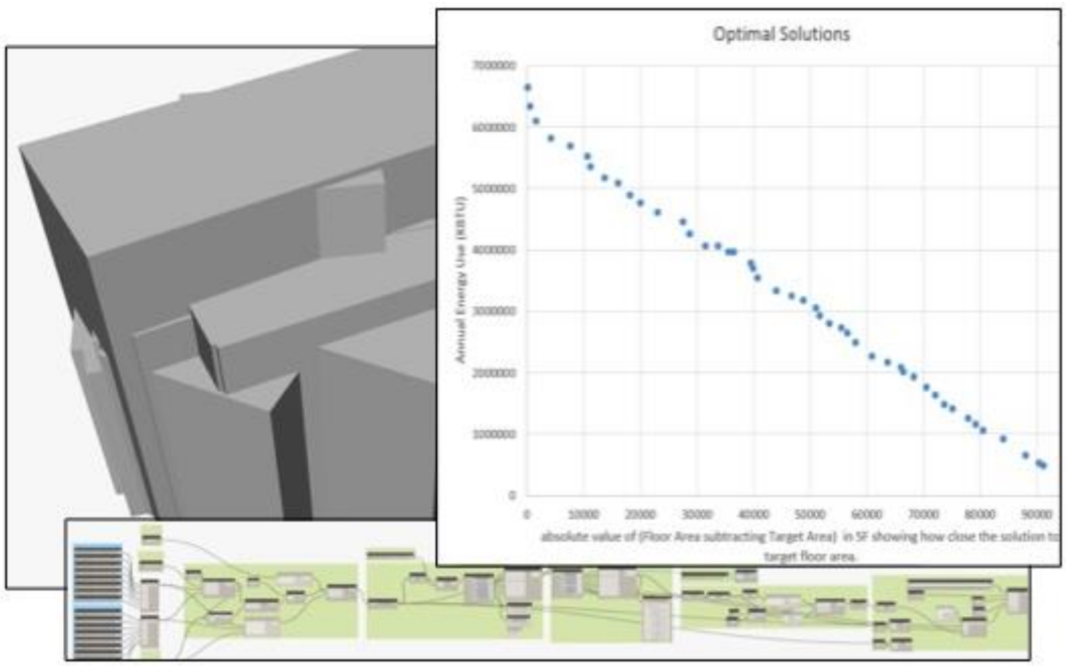

Figure 3. Design optimization graph (lower); 50 options overlaid on one another (middle); and floor area and energy performance of that population (upper right).

Data Gathering - This final step teaches students to write building parameters and measured performance metrics into a shared database. For each alternative, the Dynamo component automatically collects the student name, building volume, floor area, annual energy use, and view factor metrics and writes this information into a Google spreadsheet, using the Raindrops package (Miller, 2016), which is in turn visualized in a parallel coordinate plot on the DSC website (http://designspaceconstruction.org/), as seen in Figure 4. The analysis is discussed further in section 5.

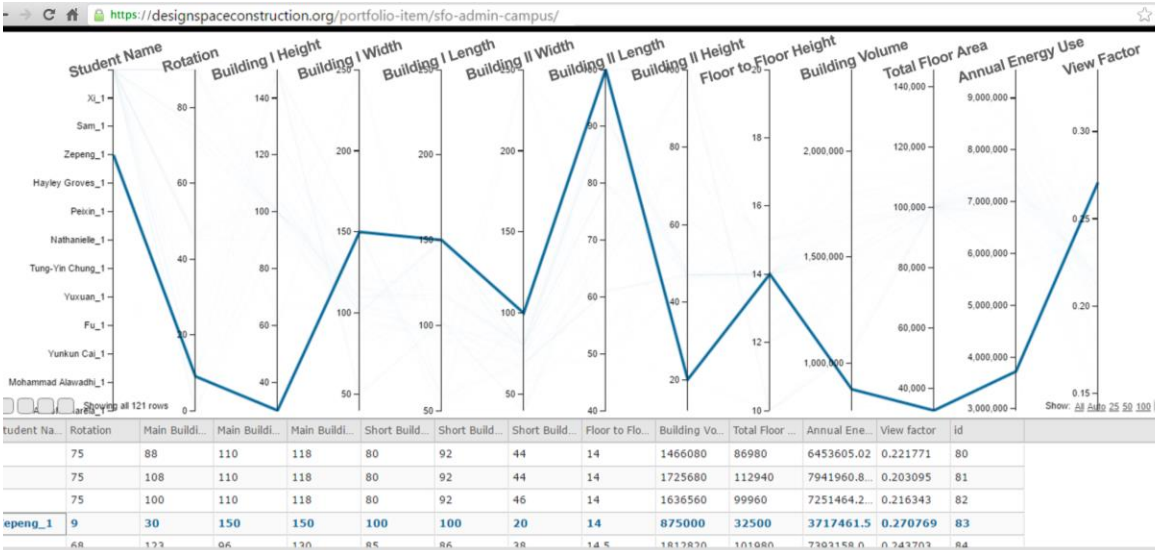

Figure 4. Parallel coordinates plot with student generated design and performance.

4 Challenge

Figure 5 shows a challenge provided by the industry professionals. It is derived from an ongoing project to design administrative office buildings at the San Francisco Airport. The benefit of using a real project is that the project constraints and goals are real, and fresh in the team's mind. Students find it motivating and relevant to work on real projects, while researchers can show impact on industry work as = research validation. The SFO Admin" challenge, which involved similar energy and view goals to those posed in the curriculum, was simplified from the challenge faced by industry to provide the right complexity for the students to handle during the short duration of the class.

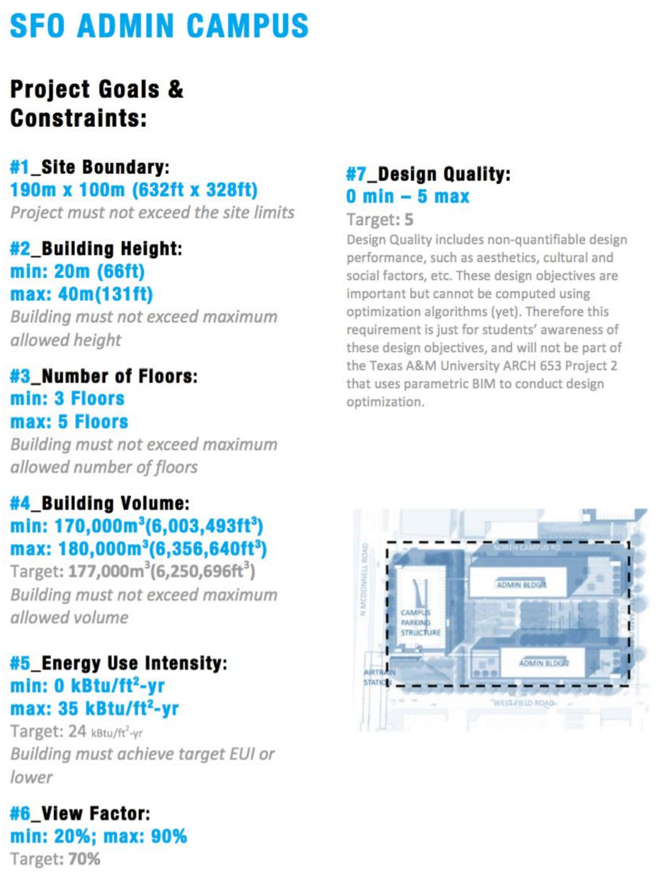

Figure 5: Industry challenge.

5 Projects

Students were asked to adapt the components taught in the curriculum to address the more realistic context provided by industry challenge. Students needed to identify and create new building parameters like number of floors, and constraints like the site boundary, modify and utilize the parametric Building Generator, and modify and define fitness functions including minimal energy use, floor area, and a view factor. Students produced the design spaces and data as shown in Figure 6-8, and uploaded the results to the DSC website.

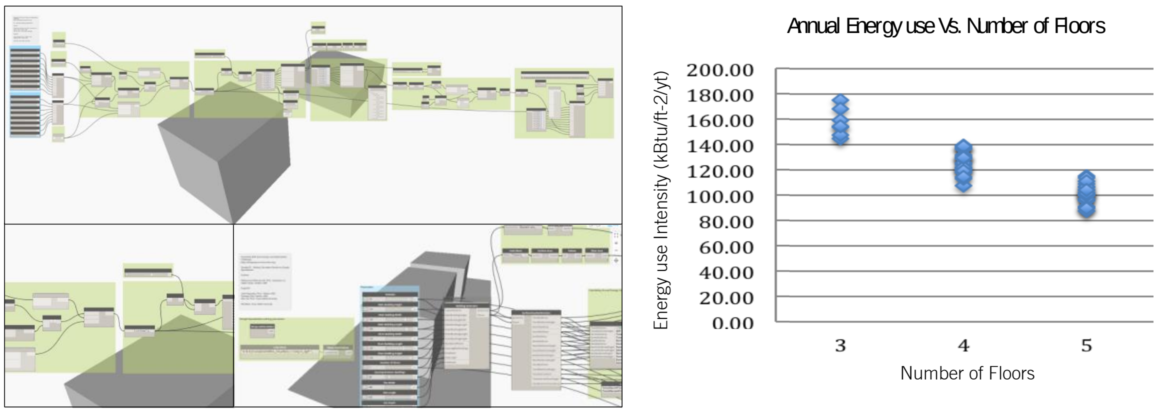

Figure 6. Left: Student project responses. Right: One design space showing relationship between number of floors and energy use.

6 Data

The DSC site collects workflows and results to inform development and selection of design space construction tools and curriculum. For example, Figure 7 demonstrates that, when working with the DSC curriculum, students working with Optimo achieved better design performance than with manual explorations - with only 5 to 20 GA generations of computing (by homework requirements), more than half of the students who submitted valid results achieved better (less) Annual Energy Use for the best floor area they made (as closer to 100,000 sf as possible) with Optimo than with their own manual explorations. Such evidence can be used to advise students and industry about the advantages of design optimization, and the comparison methodology can help choose which optimizaiton methods work best for different design challenges. Figure 8 shows the parralel coordiantes plot of all student designs, enabling identification of the design parameters that lead to the best design, and the design system that discovered those parameters.

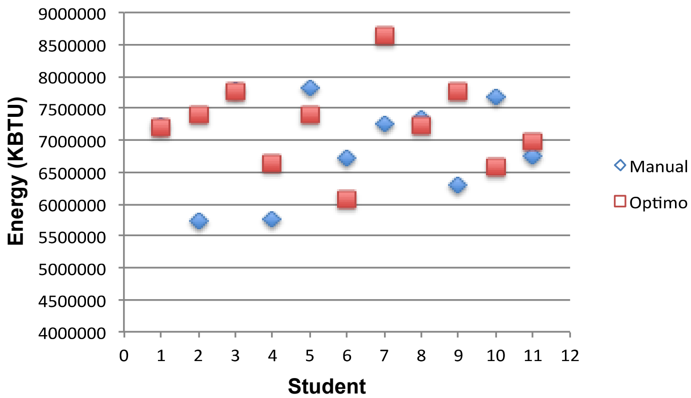

Figure 7. Students (#1, 3, 5, 6, 8, and 10) using Optimo achieved better (less) Annual Energy Use than manual exploration alone.

Figure 8. Student responses to challenge showing winning designs

Conclusions

This paper presented a case study implementation of the Design Space Construction project – a community of practitioners and researchers interested in advancing the development and deployment of design space construction and exploration methodologies. The paper demonstrated how the DSC project can work in the context of a graduate course in Building Information Modeling in Architecture, presenting prototype curricula, tools, challenges, projects, and data. Students learned that quantifiable design performance can be improved and optimized using the methods introduced in the class.

Students were also informed that design quality also includes important non-quantifiable design metrics, such as aesthetics, cultural and social factors, etc., which are not easily computed using optimization algorithms. The optimization component is one part of the BIM course, which introduces BIM principles, methods and applications in the building lifecycle with a focus on the design process. Prior to optimization, the topics include geometry and material modeling, parametric modeling, databases, visual programming, and design performance simulation and visualization. The optimization component was added into the curriculum in Spring 2016. The DSC community learned how to formulate, test, and improve the curriculum and tools through the collaborative and iterative effort.

Going forward, we aspire to do more significant experiments involving design projects with more performance objectives, such as daylight, functional space, cost, and egress. We will explore the inclusion of qualitative metrics, such as aesthetics using human judges during the evaluation process. We will also explore the inclusion of process-based metrics that measure how well a DSC method generates a wide range of alternatives or encourages broad stakeholder participation. We will be developing a common set of performance-objectives that assure common measurement criteria across projects, and a set of conclusions about which DSC methods to use for different types of challenges.

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