ADAPTIVE COLLABORATION IN PROJECT DELIVERY

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Abstract. Digital workflows in architectural design have upended traditional models of collaboration. As digitally networked tools further permeate the project delivery process, information and knowledge are increasingly distributed seamlessly across decentralized networks. While the seamless flow of information across digital networks can serve to augment traditional hierarchies of production, it can also change fundamentally the process by which architecture is produced, enabling modes of collaboration in which creation and production occur as decentralizing acts. This paper examines current models, methods and theories of decentralized collaboration in digitally networked architectural production, towards the goal of establishing a framework for understanding the meta-controls and standards that structure it. Particular emphasis is given to the emerging process of crowdsourcing, in which design intelligence emerges collectively from a decentralized network of actors and agents. This study serves as the foundation for a proposed model of ‘adaptive collaboration,’ in which an adaptive set of meta-controls and standards change in response to the evolving roles and scopes among individual actors and agents. An experiment in Adaptive Collaboration is described, taking place in a Solar Decathlon project at the New Jersey Institute of Technology.

1. Introduction

As digitally networked tools further permeate the project delivery process, information and knowledge are increasingly distributed seamlessly across digital networks. Diverse forms of information flow with little resistance through digital networks, blurring boundaries between disciplines and levelling out once pronounced distinctions between design and production (Garber, 2014). Design knowledge can be embedded, encapsulated and modularized. Digital networks absorb design information pliantly and
adaptively, forgoing traditional cycles of redevelopment and redesign as new information is introduced to a process (Woodbury, 2010).

The seamlessness of digital networks has transformed how of design intelligence emerges among disciplines and actors (Kocatürk & Codinhoto, 2009). In traditional, top-down, hierarchical approaches, different types of design intelligence are bracketed by disciplines and scopes. As digital networks render traditional boundaries frictionless, digital workflows in architecture redistribute design intelligence, reconfiguring where it resides and how it is generated. No longer associated with individual actors, design intelligence can emerge as an outcome of a dynamic process among multiple actors, models, tools, representations and systems, linked by digital networks that seamlessly distribute project information (Kocatürk, 2013). This paper proposes the model of “adaptive collaboration” for generating design intelligence across a distributed digital network, in which an adaptive set of meta-controls and standards change in response to the evolving roles and scopes among individual actors and agents.

2. Established Models of Decentralized Collaboration

The forms of collaboration in architectural design and production are closely correlated with the medium through which information is exchanged. Digital workflows allow for systems of collaboration that retain design intelligence, through the creation of interconnected, networked modules of multi-disciplinary design information (Woodbury, 2010). This process is well-established in other industries, such as automotive and aerospace, famously characterized by Kieran and Timberlake (2004) as “framing” versus “quilting,” distinguishing between a traditional, hierarchical, sequential approach, and a modular, networked approach. The types of information exchanged in both framing and quilting are substantially similar, but are distributed and redistributed through fundamentally different systems of collaboration. The information can be divided into three categories: social, model and logic-based. The structure of the medium of exchange among these sets of information can determine how collaboration occurs in a project, and how design intelligence emerges (Kocatürk, 2013).

Understanding how digital workflows are structured has increasingly become a subject of study for architects (Marble, 2012). As digital networks permeate the production process, they increasingly inform the emergence of design intelligence and digital workflows become design problems in and of themselves. Digital workflows structure the medium of exchange in digital networks and formulate how architecture is both conceptualized and produced. They increase the territory in which designers can operate, allowing diverse actors and agents to function seamlessly in a decentralized
medium, fusing machine intelligence with human decision-making (Keough & Benjamin, 2010). Historically, drawing was the primary means of communication among the disciplines involved in the production of architecture, which simultaneously and correspondingly developed as the primary tool for conceptualizing design, drawings developed to both contain and generate design intelligence (Evans, 1986). As digitally networked tools permeate the production of architecture, digital workflows likewise increasingly become both a medium of communication and a means for generating design intelligence.

One well-established approach to cultivating design intelligence in digital networks is crowdsourcing. As demonstrated in both theory and in practice, crowdsourcing is a method for generating design intelligence across decentralized networks of actors and agents (Oxman & Gu, 2012; Nolte & Witt, 2014). In crowdsourcing, design intelligence and solutions emerge from the medium of the digital production environment. Crowdsourcing utilizes social digital networks, the primary medium for generating collective design intelligence. Decentralized collaboration across the network disseminates social, geometric and logical information. Collective intelligence emerges from distributed contributions, generating design knowledge across the digital network that would not otherwise be possible in a traditional, top-down, hierarchical approach. Collaboration is structured by “command and control structures,” through “standards, norms and shared language to support the ‘interoperability’ of collective knowledge” (Oxman & Gu, 2012). These meta-controls and standards mediate the exchange of social information, digital design models and parametric logic (Oxman, 2015).

Crowdsourcing has been proven to scale well in practice on large and complex projects. In one high-profile example, the implementation of Gehry Partners’ the Fondation Louis Vuitton was enabled through crowdsourcing. To produce the elaborate, nonstandard architectural form of the building, geometrical complexity, organizational complexity, diversity of multidisciplinary scopes and hundreds of collaborators were integrated through a custom-made, web-based, building information model tool (Nolte & Witt, 2014). The platform incorporated social computing, data visualization, data mining and approval processes, as well as building simulation and near real-time optimization feedback loops. The result is a collapse of geometric, social and logical information into a single, distributed, digitally networked space (Shelden, 2013).
3. A Framework for Adaptive Collaboration

In the case of the Fondation Louis Vuitton, overall design intent was established at the onset of production, and experts from a full range of disciplines contributed to implementation, integrated through a web-based platform. The model of production however, relied on experts and disciplines that, while overlapping, were grounded within well-established and well-defined roles (Nolte & Witt, 2014).

In scenarios where roles and scopes are not well-resolved or still evolving, an alternative approach to crowdsourcing is required. These scenarios include situations in which the roles of collaborating actors and agents are subject to change, scheduling and staffing is variable, concept and fabrication processes must be developed as concurrent processes, or other conditions without well-established initial conditions. These scenarios require new command and control structures to generate distributed and collective intelligence and operate dynamically. To what extent can crowdsourcing be applied to networks in which the roles of actors and agents are dynamic and changing? In projects where the scopes of actors and agents are initially ill-defined, can an adaptive platform help resolve roles?

One approach to addressing these questions can be drawn from the disciplines of electrical and computer engineering, in which the concept of “adaptive control” is established to describe nonlinear operations that adapt to a dynamic set of circumstances (Krstic et al., 1995; Åström & Wittenmark, 1989). A classic example is flight control systems in airplanes, which can procedurally operate complex flight patterns for a single condition, but in unpredictable, unanticipated overlapping conditions, such as turbulence, change of weather or redistribution of airplane mass, a meta-controller must empirically evaluate outcomes, and reconfigure the operating parameters of the controller to adapt to new conditions. While adaptive control is generally applied to automated systems, the logic of adaptive control can be applied to the design and production of architecture by adapting meta-controls and standards, dynamically responding to unanticipated changes to the structure of collaboration among project actors and agents. Applying the logic of adaptive control to collaboration in architectural workflows, this paper proposes the process of “adaptive collaboration.” Adaptive collaboration builds on the concept of crowdsourcing, and is defined as a system for incorporating adaptive meta-controls and standards to accommodate networks of actors and agents with dynamically evolving roles and scopes.

Like crowdsourcing, which requires a robust social network, adaptive collaboration requires a network that synthesizes social, model, and logic-based information into a single platform. A platform for adaptive collaboration must be able to engage in all modes of production, from
conceptualization and design to fabrication and logistics. For these requirements, Cloud-Based Design and Manufacturing (CBDM) systems provide an ideal platform. CBDM systems are an emerging technology and represent a new paradigm for digital design and production (Wu et al., 2015). CBDM systems are software platforms that enable distributed collaboration across cloud-based digital networks, “an information communication technology system that facilitates design and manufacturing knowledge sharing between actors in the distributed and collaborative socio-technical network” (Wu et al., 2013). CBDM systems are typically distributed as a service, and are comprised of modular sets of applications designed for scalability, flexibility and re-configurability. And, because CBDM systems are an environment for facilitating manufacturing, digital mockups can be simulated for deferred production and feedback from the digital mockup can be incorporated into the design process.

4. Implementing Adaptive Collaboration

A Solar Decathlon studio at the New Jersey Institute of Technology (NJIT) has been deployed as a test case for an experiment in adaptive collaboration. Academic, virtual design studios have long played a role as incubators, testing grounds for experimental digital workflows, and are often case studies for exploring questions of how digital workflows change the nature of collaboration (Deamer, 2011; Shelden et al., 1995; Yee et al., 1998). Design studios offer a flexible, relatively risk-free environment in which to stage experiments. A Solar Decathlon studio also offers a test of multidisciplinary integration and a full-scale project delivery process, in which a series of studios conclude with the implementation of a built, zero-energy house. The Solar Decathlon studio at NJIT began with a group of 20 third-year professional degree undergraduate students, all in the formative stages of their education. The initial group of students had minimal prior experience in digital modeling, parametric design, architectural detailing or construction. The Solar Decathlon requires a wide range of specializations, from communications, to project management, to fabrication. In the earliest phases, these roles were undefined, but specializations emerged as the project evolved. For a CBDM system, the studio adopted Dassault Systèmes’ 3DExperience platform, a successor to the CATIA platform. The 3DExperience platform integrates applications for social networking, blogs postings, wikis, instant messaging, tools for digital simulation, parametric modeling, direct-to-fabrication, logical-scripting, knowledge capture and visualization tools, including virtual reality. The platform operates entirely within a cloud-hosted database. All information is seamlessly integrated into the database, with multiple access points for viewing, editing, and generating
content, including web and mobile applications. The design of the Solar Decathlon was informed by research, design discussions and other conventional approaches, but was from the onset developed through the 3DExperience platform.

The custom workflow developed for the studio centred around the concept of “components,” which were defined for the studio as parametric modelling elements integrated with other information, such as documentation or associative fabrication drawings. Components were developed in a graphical user interface through constraint-based modelling. They sometimes included integrated scripting and procedural logic, but were intended to be primarily parametrically modelled encapsulations of design knowledge. Components were comprised of individual parts, assemblies of parts, or operations to be performed on other components. For example, a component may consist of framing connection details, a structural wireframe, a panelization system, massing geometry, set of operations for extracting quantity take-offs or fabrication simulations. Components were developed for modularity and interoperability with other components. Students were assigned to initial, seed components such as massing, structure, facade or roofing. The setup was designed to allow components to evolve in tandem with student roles. As components took shape and developed increased levels of resolution, information shifted in and out of different components. A close correlation exists between component development and student development, such that while components exist primarily as parametric geometry, they also serve to integrate various social, modelling and logical information.

For example, two prototypical components involve a facade panel parametric model and a wireframe parametric of overall facade form. Initially, both the panel model and the wireframe model develop independently and with minimal complexity. As the project developed and student skills and knowledge advanced, the components grew in complexity. Ultimately, the final facade form is driven by the relationship between the wireframe and the panel, but with multiple possible outcomes. In one possible scenario, the panel drives facade form by incorporating the logic of the relationships among panels, which aggregate to shape the facade form, in turn parametrically driving the facade wireframe. In an alternate scenario, the wireframe drives the form, and the panels parametrically host on the wireframe. Over time, the panel and wireframe components subdivide into sub-components, such as framing, exterior and interior panels. This subdivision process continues as the project progresses, splitting off into smaller subdivisions of components, or recombining into new hybrids.

The interoperability of parametric components was defined at the onset by sets of geometric inputs and outputs. These inputs and outputs functioned
as standards for exchange. For example, the panel geometry may take as inputs four points, a plane and a depth parameter. This wireframe model will then be designed to output arrangements of grids of points, planes and parameters. The wireframe and panel components can be developed independently, without knowledge of the development of each other, with the expectation that the interoperability of the system will function so long as the inputs/output conditions are satisfied. The other form of collaboration standards involved specified input/output requirements. For example, a panel hosted on four points only functions if the points are not all coincident. This level of interoperability is communicated through written documentation embedded into the model database.

As components evolve over the course of the project, interoperability likewise evolves to accommodate new component relationships. Various social networking mediums were used in the platform to enable students to post work, receive markup from instructors, and for collaborator suggestions for new configurations of components. As a network of components is developed, design information begins to concentrate in some components over others. In some instances, components developed high levels of resolution while others remain underdeveloped. In other instances, components assumed functionality that superseded other components. For example, a framing component might begin to include substantial amounts of information for other components, in the form of geometric and parametric outputs. This framing component could drive a specific type of information, for example, outputting information for position, thickness, bolt locations, etc. As a result, the bracket component develops very little intelligence, and is merely the end result of the information embedded in the framing component. Redistributing design information requires identifying unbalanced conditions and making shifts to component information distribution, as well as to the meta-controls and standards that facilitate the exchange of information between them.

To control standards of exchange for this process, a system of automatic task assignment triggers was utilized, built into the scheduling system on the platform. The project schedule was linked to specific tasks, such the modelling of a parametric panel component, the completion of which would then trigger a new task assignment to another student. This task was developed as an item in the schedule that would trigger an announcement and assignment of the task to the student representing the panel. Assigned tasks remained active until they were completed, at which point the next task was assigned automatically by the schedule. The status of all tasks, completed and active, is viewable in a web-based dashboard in the platform. Schedule and 3D models in progress can likewise be viewed from the dashboard. Task assignments also include information about parametric
input and output geometry, which can be revised as components develop. By actively reviewing the dashboard for progress, weak links in project development can be identified, and the schedule of task assignment correspondingly adapted.

As the project progressed, students developed strengths and specializations within specific areas of the project. Certain students became proficient in parametric modeling, for example, and were highly productive in generating new components, while other students focused on research and documentation that informed the components. Identifying trends and patterns in the evolution of roles was important to maintaining collective productivity and efficient collaboration. Individual discussion with students was a part of evaluating roles, but would not always reveal collective trends and patterns in advance or accurately characterize individual or group roles. Moreover, some necessary roles remained underdeveloped, such as a focus on specific building components or documentation production, and needed to be identified. To support an understanding of how design intelligence was emerging from the network, web-based dashboards in the platform that aggregate live production data were used by both instructors and students to assess trends and patterns in role development. Web-based dashboards were used to review live, collective statistics on data, such as how the production of component or documentation was occurring across the studio, the distribution of components types being created, and time spent by individual students on developing components.

5. Discussion

The evaluation of statistical data through web-based dashboards allowed meta-controls and standards to be adjusted both in response to evolving roles, and to manage and shape them. This included defining and redefining the exchange standards of geometric inputs and outputs for parametric model components, identifying and enabling student specialization, redistributing production time among components, defining and allocating new task assignments, adapting the schedule, and identifying gaps in production resources. The meta-controls and standards were part social, part model and part logical. Taken together, they allowed for collaboration to occur similar to crowdsourcing, as a decentralized system for generating design intelligence, but with a dynamic evolution of the roles of the actors within the project. The web-based dashboards and scheduling, as well as the web-based model viewer, allowed persistent review of project data and statistical trends from a granular level to an overview level. The information gathered from collective data, supplemented with individual review, offered a far more thorough understanding of the how design intelligence was emerging
and being produced than in a typical studio process. This understanding allowed for a more efficient distribution of resources and time, as well as allowing for a more flexible and dynamic, adaptive approach to project development than could otherwise occur.

Deeper understanding of the extensive data revealed through the platform dashboards remains a site for further investigation. Trends in data did not always correlate with expected interpretations and the degree to which meta-controls and standard should be specific must be balanced with flexibility. Many opportunities exist to test adaptive collaboration in new projects. The incorporation of machine agents into the process is an additional area for further study. Workflows that integrate computational optimization have already proven to expand the territory in which designers operate (Keough & Benjamin, 2010). Can collaboration be adaptively controlled by procedural logic? As artificial intelligence increases in sophistication, could it play a role in structuring meta-controls and standards? The current study remains primarily a human-operated and -managed system of adaptive collaboration, but new territory exists to be explored with the application of procedural logic, optimization and machine learning.

6. Conclusion

The evaluation of data generated through CBDM platform-based workflows are well established in other industries, where they have enabled highly efficient practices and smart factories (Wu et al., 2013). Architectural workflows, as has been discussed above, have widely different methods, distribution of multidisciplinary expertise and requirements for adaptability in production. To maintain agency for design within a system tailored for efficiency, architects must understand how command and control structures influence collaboration, and take an active role in structuring how design intelligence is generated.

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