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Improving Design Processes through Collaborating, Sharing, and Understanding

By

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CIFE Seed Proposal
2009-2010 Projects

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Abstract (up to 150 words): Previous research defines a Design Process Communication Methodology that specifies an organizational and technological environment necessary for improving the efficiency and effectiveness of design processes. From Points of Departure in Human Computer Interaction, Knowledge Management, Process Modeling, and Design Theory, the authors have derived specifications categorized by the characteristics: Transparent, Modular, Searchable, Usable, Scalable, Incentivized, Computable, and Framed. This proposal seeks support for deploying the Process Integration Platform (PIP) web tool to measure the impact of this methodology. The proposal explains how the authors intend to use PIP in student and professional design charettes, and professional case studies to measure impact on defined metrics for process efficiency and effectiveness. The authors hypothesize that the resulting improvements to efficiency and effectiveness will increase the financial, environmental, and social value delivered by the AEC industry.

0 Introduction

This research aims to derive financial, environmental, and social value from more efficient and effective design processes communication Design processes disproportionately influence the life cycle value of the resulting products (Paulson 1976). Thus, while the total cost of design is relatively small, the design phase of a project greatly influences total project value. Despite major advances in information technology over the past fifty years, the value per man-hour expended, productivity, actually decreased from 1964 to 2003 (United States Department of Commerce 2003). As construction project's final value is most influenced by design, the architecture, engineering, and construction (AEC) industry can improve value per man-hour expended most directly by improving design processes.

Design is an aggregation of many information exchanges between people within and between organizations. Jin and Levitt's Virtual Design Team (1996) similarly applied this information processing view of the organization to the AEC industry first described by Weber in 1920 (1997) and later adopted by March and Simon (1958) and Galbraith (1977).

Inefficient and ineffective information exchange contributes to construction productivity stagnation. The National Institute of Standards and Technology (NIST) report (Gallaher et al. 2004) confirms that information flow on AEC projects are inefficient and intermittent. Extrapolating, McGraw Hill estimates the global AEC industry wastes $138 billion annually due to software interoperability problems, which comes at the expense of meeting financial, environmental, and social project goals (Young et al. 2007).

At the same time poor information exchange reduces a project's total value, the cost of resources required to obtain that value is increasing. Buildings consume 70% of the U.S.'s electricity, 40% of raw materials, and 12% of water (USGBC 2007). Exploding population growth will require more building which requires more resources, increasing their relative cost. More buildings increase society's negative impact on the environment. As populations expand and population density increases, a single project impacts more stakeholders. The AEC industry has a responsibility to improve design processes to ensure limited resources are applied optimally with respect to financial, social, and environmental value.

At least three methods exist that permit organizations to improve design processes:

1. Design firms use more tools, to decide between more building technology options, to meet the performance goals of more stakeholders. These trends provide an opportunity to design more valuable buildings, but traditional collaboration methods limit this realization. To improve design processes in this complex environment, designers need a methodology that enables ***collaboration*.**

2. Project teams around the world face the same financial, environmental, and social challenges, and continuously develop new and different methods to overcome these challenges. To learn from how others address these problems, design teams need a methodology that promotes ***sharing*.**

3. Developing new design processes requires investment, which requires a claim that the return will be an improvement on the current state. In other words, if a design team does not understand the inefficiency and ineffectiveness of their current process, they will not invest in improvement. Design process innovation requires a methodology for design process ***understanding***.

Collectively, this research define collaborating, sharing, and understanding, *design processes communication.* (Senescu et al. 2008) proposes a design process communication methodology that specifies an organizational and technological environment necessary for improving the efficiency and effectiveness of design processes. Senescu and Haymaker (2008) describes the Process Integration Platform (PIP) web tool. In this Seed proposal, the authors seek support to deploy and test this methodology and tool. The proposal explains how the authors intend to use PIP in student and professional design charettes, and professional case studies to measure the impact of the Design Process Communication Methodology.

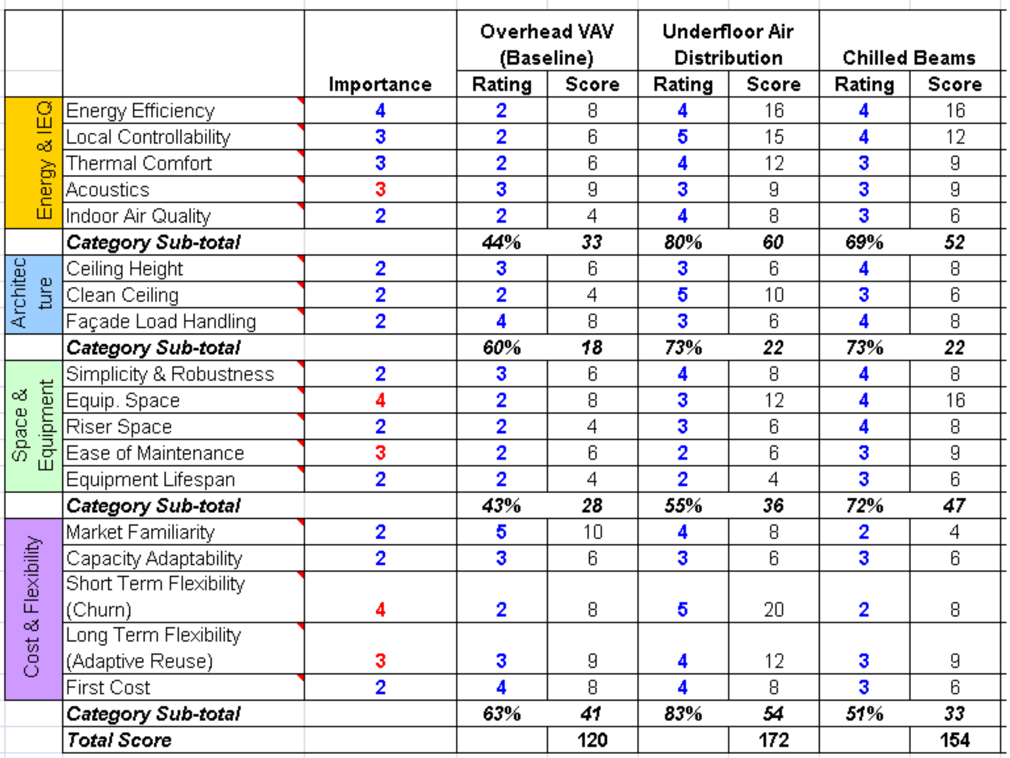
The next section gives specific examples of how current design process communication limits design process improvement.

1 Motivating Business Problem

This proposal uses the design of the Stanford Graduate School of Business (GSB) campus to provide examples of challenges faced by multi-disciplinary design teams. As structural engineer on this project, Reid Senescu gathered design process information directly and through interviews.

1.1 Designers struggle to collaborate

When designing the GSB, researchers identified six discrete stakeholder groups with 29 project goals.[1] The design team evaluated seven mechanical heating/cooling options with respect to a subset of these stakeholder goals (Figure 1).[2] They divided one building into five different zones and assigned five of the seven mechanical options to these zones (Figure 2). The process of assigning these cooling/heating technologies to the building is complex. According to the matrix the under floor distribution system is the best choice. However, the floor plan shows that in many cases other options prevailed. Predicting how multiple options perform with respect to multiple goals in different contexts requires the design team to synthesize information from multiple tools that output multiple measurements.[3]



			Overhead VAV (Baseline)		Underfloor Air Distribution		Chilled Beams	
		Importance	Rating	Score	Rating	Score	Rating	Score
Energy & IEQ	Energy Efficiency	4	2	8	4	16	4	16
	Local Controllability	3	2	6	5	15	4	12
	Thermal Comfort	3	2	6	4	12	3	9
	Acoustics	3	3	9	3	9	3	9
	Indoor Air Quality	2	2	4	4	8	3	6
	Category Sub-total		***44%***	***33***	***80%***	***60***	***69%***	***52***
Architecture	Ceiling Height	2	3	6	3	6	4	8
	Clean Ceiling	2	2	4	5	10	3	6
	Façade Load Handling	2	4	8	3	6	4	8
	Category Sub-total		***60%***	***18***	***73%***	***22***	***73%***	***22***
Space & Equipment	Simplicity & Robustness	2	3	6	4	8	4	8
	Equip. Space	4	2	8	3	12	4	16
	Riser Space	2	2	4	3	6	4	8
	Ease of Maintenance	3	2	6	2	6	3	9
	Equipment Lifespan	2	2	4	2	4	3	6
	Category Sub-total		***43%***	***28***	***55%***	***36***	***72%***	***47***
Cost & Flexibility	Market Familiarity	2	5	10	4	8	2	4
	Capacity Adaptability	2	3	6	3	6	3	6
	Short Term Flexibility (Churn)	4	2	8	5	20	2	8
	Long Term Flexibility (Adaptive Reuse)	3	3	9	4	12	3	9
	First Cost	2	4	8	4	8	3	6
	Category Sub-total		***63%***	***41***	***83%***	***54***	***51%***	***33***
	Total Score			**120**		**172**		**154**

Figure 1: An abridged decision matrix showing three of seven options and a subset of goals. The matrix suggests that underfloor air distribution best meets the goals, but of course, different systems are best in different context. The designers do not have a tool to represent this complex interaction.

The result of this informal process caused the owner representatives to, in their own words, "feel lost with so many options for the mechanical system." The representatives described the decision as "mixed and unclear" with "a lot of data." The representatives "expressed their concern about inequity in the mechanical system decision, specifically the potential inequity between faculty offices." The owners did

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[1] Many projects have substantially more stakeholder groups. For example, on a hospital project we found 41 stakeholder groups with 33 goals.

[2] At this point in design, geometry was fixed. A recent stadium project produced 20^{1955} variations (Flager 2009).

[3] The firm designing this mechanical system recently found that they use 197 sustainability design tools and 189 structural design tools.

not understand how to interpret the data with respect to stakeholder goals. The representatives also felt they "need more data" for "stronger justification" of the mechanical system decisions. The designer process was not sufficiently transparent such that the owners found the design team's recommendation convincing.

Comprehending this decision was too complex just within mechanical engineering. In reality, the decisions also impact acoustics, lighting, and structural engineering. With current tools, both the owners and designers did not systematically consider the complex impacts of one decision on multiple disciplines. The multi-disciplinary design team did not maintain consistency among information. The design team struggle to comprehend and manage their information dependencies; they struggle to *collaborate.*

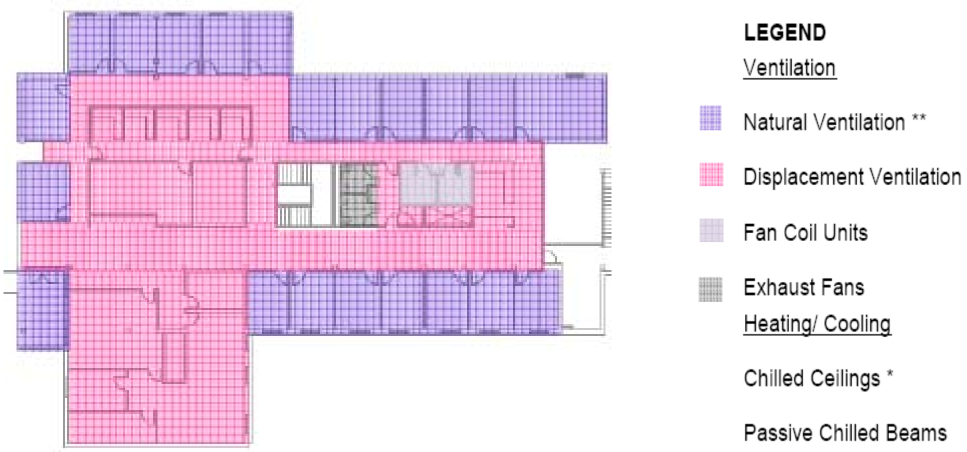

Figure 2: Mechanical zone plans did not convince the owners that the this layout was correct. The zone plans were not consistent with other documentation, which made it difficult for other disciplines to coordinate with the mechanical engineers.

1.2 Designers struggle to share processes

The stakeholders communicated the importance of material responsibility when choosing structural systems. The structural engineer created schematic Revit Structure models of steel and concrete options. The engineering firm had recently purchased Athena, software that uses a database to output the environmental impact of building materials. Despite a 3d object oriented model (containing a database of structural materials and quantities), a database of the environmental impacts of those materials, and a desire by the stakeholders to consider material responsibility in their design decision, the structural engineer was unable to conduct an environmental impact analysis comparing the concrete and steel options.

Several months later, the structural engineer met a researcher in California that had worked with the Cooperative Research Centre for Construction Innovation in Australia to develop a process for performing model-based assessments of the environmental impact of construction materials. In fact, the research centre worked directly with the Australian offices of the same engineering company.

In this case study, a clear demand for an improved process existed in the California office. The engineer could not find a design process to compare options with respect to stakeholder goals, even though researchers in California and engineers from the same company in Australia had already performed this process (Tobias and Haymaker 2007). A 2008 survey (Senescu and Haymaker 2008) confirmed the generality of this problem: designers struggle to *share* processes.

1.3 Designers struggle to understand processes

With the goal of informing the design team's decision regarding the quantity and size of louvers on the south façade of the GSB, daylighting consultants created video simulations of sunlight moving across a space (Figure 3). Looking to improve the realism of the output, the consultants discovered they could use the process described in (Senescu and Haymaker 2008). As described in Senescu and Haymaker (2008), this process was inefficient, no one was developing an improved process, and the author could not find an improved solution. The consultants' supervisors, software developers, and their clients had no methods for understanding how an improved process could increase profits or design quality. With an investment of $2400, Senescu and Haymaker (2008) estimates $32,400 of added value annually. Senescu extrapolates that further investment could add $97 million of value to the firm annually through more efficient and effective analysis processes.

Figure 3. Snapshot of a QuickTime video. The consultants use this video to show the architects how different louver configurations affect daylighting in the GSB.

The current tools provide an opportunity to improve the efficiency and effectiveness of the lighting design process. Yet, individual consultants are not incentivized to invest their time in process improvement. Their tools do not track their process (and the resulting inefficiency), place them in a small peer community to improve the process together, nor provide transparent access to other processes that could form the basis for improvements. Also, managers lack a transparent method for understanding the inefficiency and therefore, lack a monetary justification for encouraging development of alternatives.

2 Intuition

Building Information Modeling (BIM), performance-based analysis tools, internet technologies, integrated project delivery methods, globalization, increasing acceptance of the importance of environmental and social goals, cloud computing, and cultural shifts in our relationship with technology both permit and necessitate disruptive design process innovation. Meeting the financial, environmental, and social goals of increasingly numerous stakeholders, in a resource-limited world will require a methodology for design process communication to lay the foundation for the next generation of web-based information management tools. The methodology must specify an organizational and technological environment necessary for improving the efficiency and effectiveness of design processes. The next section identifies points of departure for developing this methodology.

3 Points of Departure

Taylor and Levitt (2004) explain that the implementation of new processes across multiple firms (systemic innovation) diffuses slowly in AEC. By synthesizing findings in the engineering fields of knowledge management, process modeling, human computer interaction (HCI), and design theory, Senescu and Haymaker (2008) develop a methodology for design process communication to overcome the diffusion barriers explained by Taylor.

From the knowledge management field, this research extracts successful *methods for capturing, organizing, and disseminating knowledge*. Grant (1996) states that organizational knowledge is a resource. In this knowledge-based theory of the firm, the organization transforms knowledge into economically rewarded products and services (Will and Levitt, 2009), Grant 1996 and (Khanna et al. 2005)). For example, organizations transform knowledge of building design processes into buildings. By improving the collection and distribution of this design process knowledge, this research improves building value. Our proposed methodology allows designers to codify knowledge (Hansen et al. 1999) about design processes so designers can reuse this explicit knowledge (Will 2008) and modularize existing processes to create innovative new processes (Hargadon and Bechky 2006).

In the process modeling research field, Lee (2007) uses process models to improve product data models – a formal definition of product information. Lee, identifying several drawbacks to current product modeling method, argues that product models must have a closer linkage with workflow and that mapping between processes and the product model data should become an explicit part of the definition activity. Prior research at CIFE addresses this claim, but falls short in other areas. For example, Geometric Narrator (Haymaker 2006) enables a designer to build a scalable, computable process from sub processes, but lacks an intuitive visual interface and mechanisms to easily share and collaborate. Narratives are formal, visual descriptions of the design process that include representations, reasoning, and their interrelationships (Haymaker 2006).Narrator addresses the communication deficiencies of Geometric Narrator, but at the expense of its integration power. Our research synthesizes the benefits of all of these methods.

HCI research describes ways computers best aid and supplement human and organizational capabilities. HCI research suggests it is necessary to filter the vast amount of project information to a humanly comprehensible scale to aid the user in transforming this information into design process knowledge. Minsky (1974) proposes, "Whenever one encounters a new situation (or makes a substantial change in one's viewpoint) he selects from memory a structure called a frame …. A frame is a data-structure for representing a stereotyped situation…" The frame acts as a medium to transform the vast amount of dependency information in a project's database into a filtered information dependency graph (a type of process map) that permits the user to obtain knowledge about the design process.

Within design theory, Ishino and Jin (2006) state that knowing how designers carry out designs provides "designers with valuable insights to effectively handle design tasks without diverting too much of their design efforts." Generally, they learn design know-how knowledge through implicit learning. Ishino and Jin (2006) point out that few researchers have attempted to capture "know-how knowledge," such as design procedures. The reasons are similar to challenges faced by design rational researchers, Moran and Carroll (1996), who explain that designers struggle to document their rationale.

Our research will demonstrate whether previous explanations for barriers to systemic process innovation in AEC can be overcome by drawing from these research fields to develop a new emergent methodology for design process communicating. As the demands on designs become increasingly complex to meet the needs of diverse stakeholders given increasingly limited resources, it is critical AEC has an underlying methodology for instantiating systemic process innovation in the industry. The authors hypothesize that this new methodology will lay the foundation for this systemic innovation.

4 Research Question

Our research broadly tries to answer the question: answer the question:
How does a theoretically-founded[4] Design Process Communication Methodology impact the efficiency and effectiveness of design processes[5]?

Having nearly completed the definition and implementation of the methodology, this proposal seeks support to measure impact.

5 Research Method

The research method, described in, uses the charette research method (Clayton et al. 1998)and industry case studies to validate my contribution to knowledge. This seed proposal requests funding for completion of the modeling (6b), testing (6c), and validation (7) phase.

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[4] The methodology is developed by aggregating research findings in Knowledge Management, Process Modeling, Human Computer Interaction, and Design Theory.

[5] Building design processes from concept design to construction documentation.

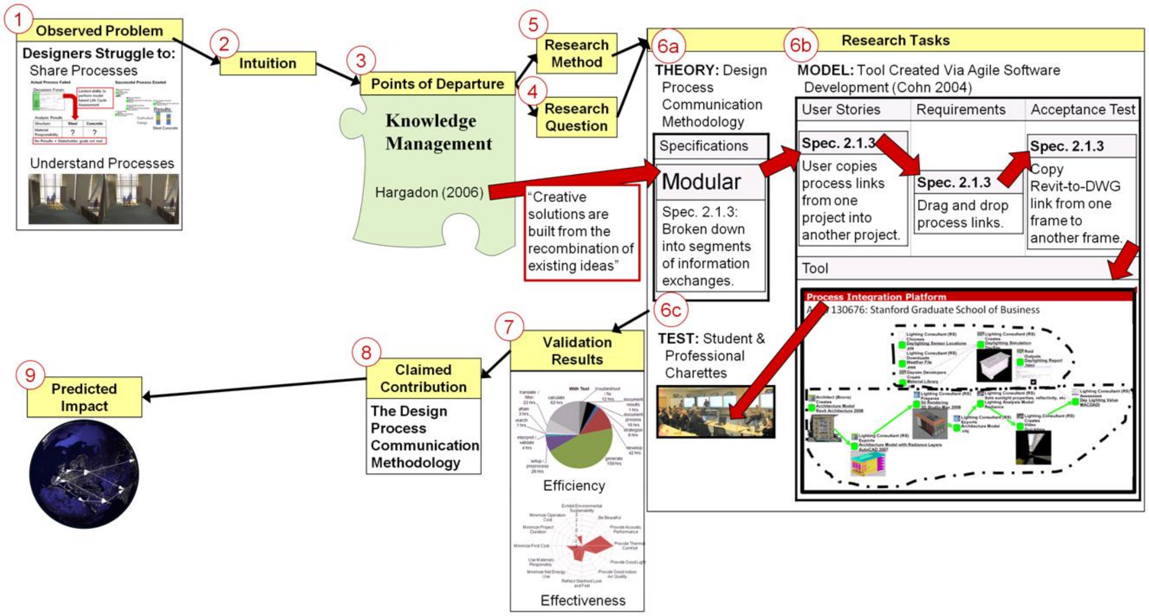


Figure 4: This figure maps the research process to the CIFE horseshoe. (1) The authors observe a Problem in designer's ability to collaborate, share, and understand. (2) The Intuition is that process-oriented information management systems can improve this communication problem. By reviewing the (3) Points of Departure, the authors identify gaps in Design Management research's ability to address this Observed Problem. The Points of Departure lead to a (4) Research Question and a (5) Research Method to fill this gap. In addition, Points of Departure in other fields inform the development of a methodology. For example, in the Knowledge Management research field, Hargadon claims that creative solutions require modularity, so this point is mapped to a specification in the methodology. The first Research Task is to aggregate these points of departure and develop the (6a) Design Process Communication Methodology. The methodology is composed of theoretically-founded specifications of a technical and social environment that improves design processes (6b). To model this methodology, the authors use Agile Software Development (Cohn 2004) to create a tool that implements the specification. For example, using this method, the authors map the Methodology specifications to User Stories and then to Requirements. A software architect then creates a web tool and the Acceptance Tests confirm that the tool meets the requirements. Thus, Hargadon's original claim of modularity becomes a software feature allowing users to drag and drop existing information exchange links into a new design process. The research uses the web tool to (6c) test the Methodology in student and professional charettes. This final research tasks produces metrics determining the impact of the Methodology on design process efficiency and effectiveness, (7) Validation Results. The authors then claim this Design Process Communication Methodology as a (8) Contribution to the Design Management research field. (9) The authors predict that this Design Process Communication Methodology will impact industry by providing the foundation for development of more sophisticated tools to improve design process efficiency and effectiveness through improved communication.

6 Research Tasks

6.1 Theory: The Design Process Communication Methodology

From the Points of Departure (including but not limited to those references discussed in Section 3), Senescu and Haymaker (2008) extract characteristics of the design process communication methodology (6a). For example, Hargadon (2006) found that "creative solutions are built from the recombination of existing ideas." From this finding, Senescu claims the environment for design process communication must be modular. Senescu achieves modularity with a specification to "Break processes into segments of information exchanges." A collection of similar specifications organized by characteristics (Transparent, Modular, Searchable, Usable, Scalable, Incentivized, Computable, and Framed) make up the methodology described in Senescu and Haymaker (2008).

6.2 *Model: The Process Integration Platform*

To validate the design process communication methodology, the authors develop a process-based information management web tool based on the methodology specifications. The agile development method (Cohn 2004) provides a framework for mapping user stories to software features. Thus, based on the methodology specifications for the social and technological environment, the authors develop corresponding user stories. For example, the specification about modularity becomes, “User copies process links from one project into another project.” The user story is then supplemented with requirements (e.g. the copying must be possible through drag and drop) and acceptance tests. The acceptance tests provide an objective method for assessing whether the tool meets the users stories. A software architect then creates a tool based on the user stories. In this way, the tool acts as a proxy for the methodology. The web-based tool (Figure 5), Process Integration Platform (PIP) is described in (Senescu and Haymaker 2008) and (Senescu et al. 2008) and the ongoing development wiki (Senescu 2009). An incomplete prototype (Release 1) is visible at http://processes.stanford.edu.

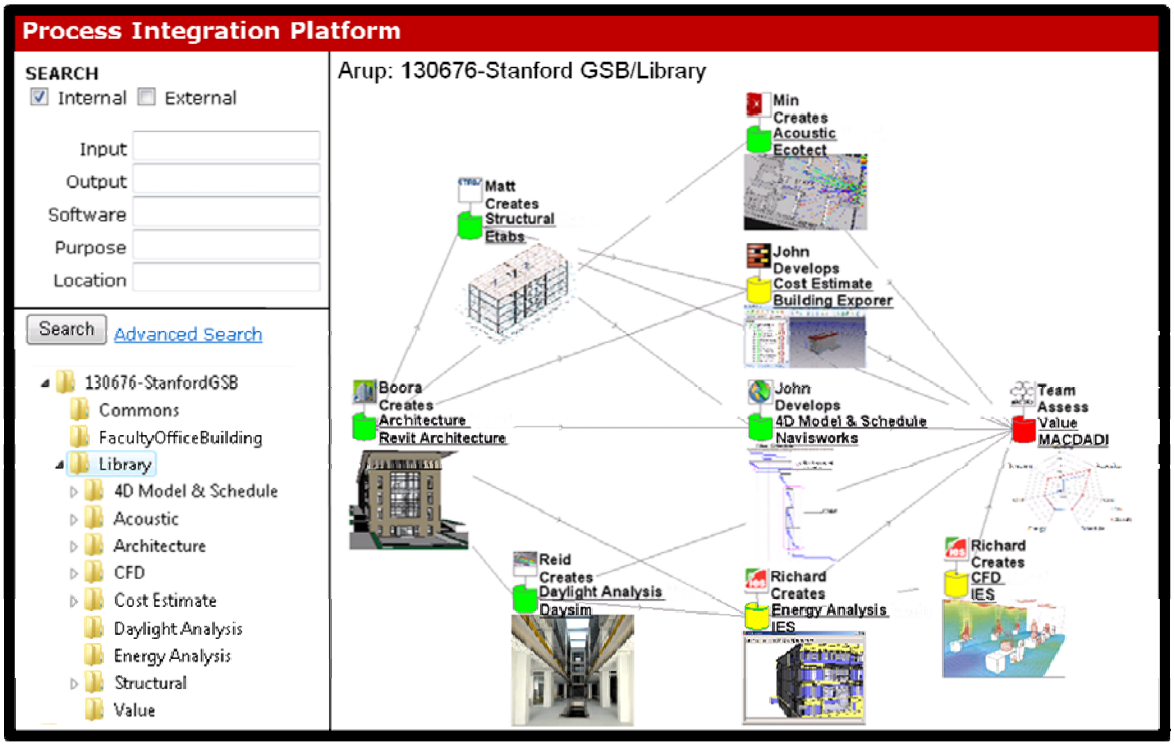
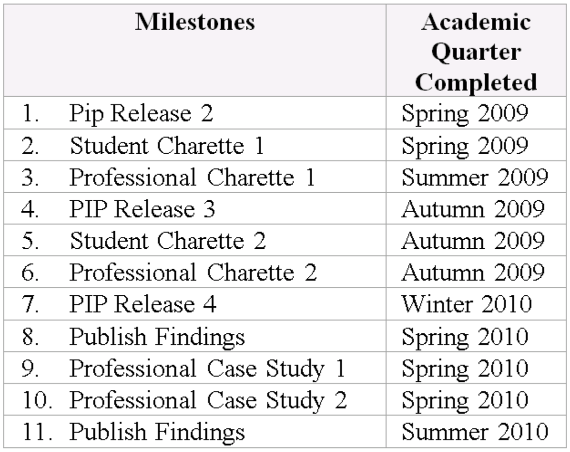


Figure 5: A prototype of the Process Integration Platform was used to manage information on the GSB. The research uses PIP to test the impact of of the Design Process Communication Methodology.

6.3 *Test: Charettes and Case Studies*

The Seed investment will support the authors and Nam Wook Kim (a Computer Science graduate student) to further develop PIP in order to validate the methodology with two types of charettes and at least two case studies. After each test, the authors will refine the methodology and the corresponding model (PIP) based on learning from the tests. Table 1 identifies the major milestones.

Table 1: *Schedule of Milestones*

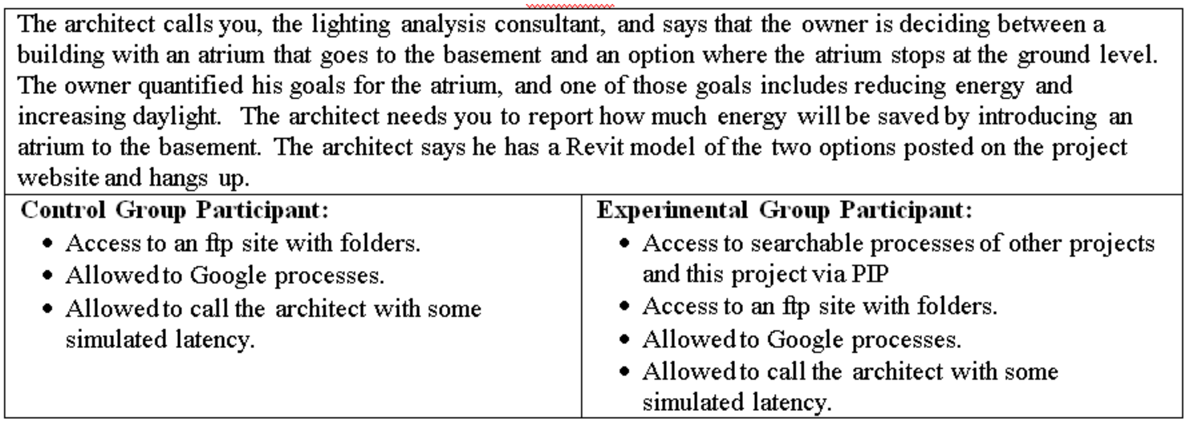


Milestones	Academic Quarter Completed
1. Pip Release 2	Spring 2009
2. Student Charette 1	Spring 2009
3. Professional Charette 1	Summer 2009
4. PIP Release 3	Autumn 2009
5. Student Charette 2	Autumn 2009
6. Professional Charette 2	Autumn 2009
7. PIP Release 4	Winter 2010
8. Publish Findings	Spring 2010
9. Professional Case Study 1	Spring 2010
10. Professional Case Study 2	Spring 2010
11. Publish Findings	Summer 2010

6.3.1 Charette 1: Impact of Sharing on Efficiency

The participant is presented with the scenario in Table 2.

Table 2: Charette 1 Scenario



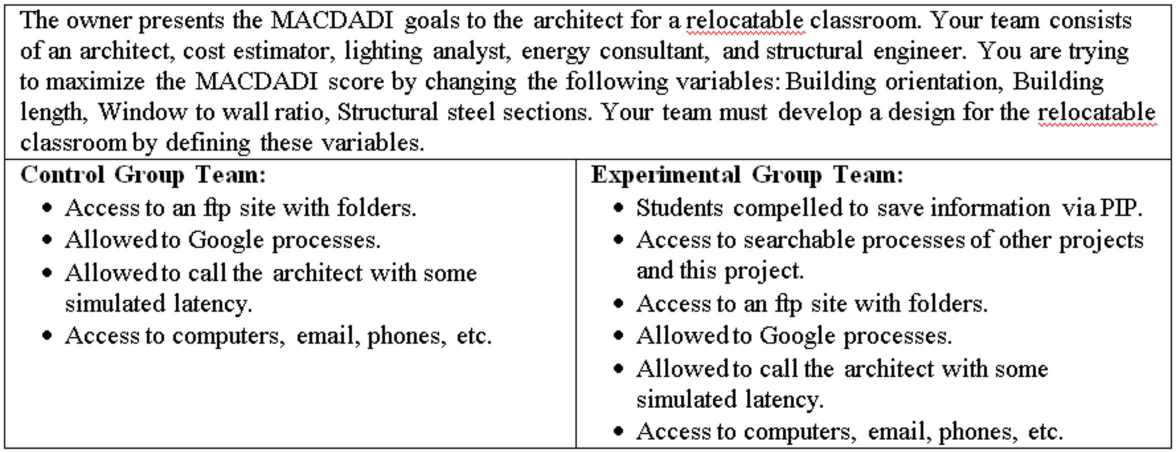
<table>
<tr><td colspan="2">The architect calls you, the lighting analysis consultant, and says that the owner is deciding between a building with an atrium that goes to the basement and an option where the atrium stops at the ground level. The owner quantified his goals for the atrium, and one of those goals includes reducing energy and increasing daylight. The architect needs you to report how much energy will be saved by introducing an atrium to the basement. The architect says he has a Revit model of the two options posted on the project website and hangs up.</td></tr>
<tr><td>Control Group Participant:
• Access to an ftp site with folders.
• Allowed to Google processes.
• Allowed to call the architect with some simulated latency.</td><td>Experimental Group Participant:
• Access to searchable processes of other projects and this project via PIP
• Access to an ftp site with folders.
• Allowed to Google processes.
• Allowed to call the architect with some simulated latency.</td></tr>
</table>

Each participant's process is measured by a screen capture and time stamp. The participant is required to enter a value for energy savings by introduction of the atrium. If the value is reasonably accurate, the process efficiency is measured. By looking at the activities being performed, time spent per is recorded. From this breakdown, process efficiency is measured (Equation 1) for each group and compared. The charette measures whether the methodology improves process efficiency through sharing of design processes.

6.3.2 Charette 2: Impact of Collaborating and Sharing on Efficiency and Effectiveness

A team of five participants are presented with the scenario in Table 3. The authors measure efficiency as in Charette 1. The authors also determine the MACDADI score, Designer Review and Option Generation. These three metrics are inputted into Equation 2 and the percentage change in effectiveness of the Control Group is compared to the Experimental Group. The charette measures the impact of collaborating and sharing on design process efficiency and effectiveness.

Table 3:*Charette 2 Scenario*



<table>
<tr><td colspan="2">The owner presents the MACDADI goals to the architect for a relocatable classroom. Your team consists of an architect, cost estimator, lighting analyst, energy consultant, and structural engineer. You are trying to maximize the MACDADI score by changing the following variables: Building orientation, Building length, Window to wall ratio, Structural steel sections. Your team must develop a design for the relocatable classroom by defining these variables.</td></tr>
<tr><td>Control Group Team:
• Access to an ftp site with folders.
• Allowed to Google processes.
• Allowed to call the architect with some simulated latency.
• Access to computers, email, phones, etc.</td><td>Experimental Group Team:
• Students compelled to save information via PIP.
• Access to searchable processes of other projects and this project.
• Access to an ftp site with folders.
• Allowed to Google processes.
• Allowed to call the architect with some simulated latency.
• Access to computers, email, phones, etc.</td></tr>
</table>

6.3.3 Case Studies: Impact of Collaborating, Sharing, and Understanding on Efficiency and Effectiveness

For any one company the authors will measure processes on two projects with and without use of the methodology. The control group will have no interventions. The experimental group will use PIP for collaboration, sharing and understanding.

For the control group, the authors will interview members of the project team to map their design processes and code their tasks retrospectively to determine process efficiency according to Equation 1. For the experimental group, the authors will code tasks according to the processes they record in PIP. For both groups, the authors will calculate effectiveness according to Equation 2. By comparing the two groups, the authors measure the impact of collaborating and sharing on process efficiency and effectiveness.

Measuring the impact of understanding is more challenging, because investment in improved processes due to better understanding takes place over several projects. Throughout the case study observation period, the authors will look for examples of investment in design process improvement and evaluate whether the design process communication methodology impacted this investment through better understanding (See Section 10.2 Next Steps).

Industry Involvement: The authors have currently written a separate proposal to use PIP on a stadium project with a CIFE member. Other CIFE industry partners are invited to contact the authors to participate in a case study.

7 Validation Metrics

Do designers with the design process communication methodology perform more efficiently? Senescu and Haymaker (2008) describes in detail metrics for measuring efficiency and effectiveness. By tracking the amount of time spent on each task, the authors determine the percentage change in design process efficiency due to introduction of the methodology. The percentage change in efficiency is defined as:

$$\Delta\ \textbf{Efficiency} = \Delta\ \textbf{(Value Added Time / Total Process Time)}$$

Equation 1

From this equation, the authors compare the relative efficiency of various processes currently in practice and measure whether P.I.P. improves efficiency. Senescu and Haymaker (2008) also explains how to measure design process effectiveness:

$$\Delta\ \textbf{Effectiveness} = \textbf{50\% x } \Delta\ \textbf{MACDADI + 25\% x } \Delta\ \textbf{Designer Review + 25\% x } \Delta\ \textbf{Option Generation}$$

Equation 2

8 Expected Contribution

Section 3 describes how research in Human Computer Interaction, Process Modeling, and Knowledge Management provide points of departure for contributing a design process communication methodology to the Design Management research field. By measuring the impact of the theoretically founded design process communication methodology, I contribute to the design management research field.[6] The contribution is validated by measurements of its impact on design process efficiency and effectiveness.

9 Industry Impact: Relationship to CIFE goals

PIP promotes design process sharing. By bringing together global design processes in a common language, PIP allows companies to more easily take innovative processes from other countries and appropriately apply them to their design.

Sustainability requires design integration. PIP permits the project team to collaborate to make more informed multi-disciplinary decisions to ensure that designs meet stakeholder's sustainability goals.

Project teams rarely fully collaborate sufficiently to predict the cost impact of their decisions on other disciplines. By mapping out information for the entire project, participants can conform costs to the budget by avoiding unforeseen design impacts.

Similarly, seeing the impact of design decisions or changes on other disciplines reduce the likelihood of schedule delays. Moreover, increased sharing of design processes and design process integration ensures that the project team is using the best design process available; therefore shortening the schedule.

10 Appendix

10.1 Risks

Testing the methodology is dependent on completion of PIP. Currently, a software architect and Nam Wook Kim are preparing PIP for testing. The milestone schedule presented here is dependent on the PIP development schedule at (Senescu 2009). Testing is also dependent on willing participants and member companies willing to volunteer case studies.

10.2 Next steps

The impacts of understanding on design process efficiency and effectiveness requires measurement across projects and possibly, over periods of more than one year. After completing this phase of research, the authors will track the long-term impacts of the case studies to see if they prompted investment in better processes. Flager et al (2008) seeks to automate processes using Process Integration Design Optimization software. By integrating PIP with PIDO and other process automation software, the authors intend to support and measure measure the impacts of communicating automation and optimization methods.

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[6] This research strategy follows the "broad jump" approach, whereby research contributions can be made regardless of the results (Levitt, R. E. "Research Methodology in Facility Engineering: Introduction." *ASCE Construction Research Council - Workshop on Research*, Hilton Head, SC.).

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