Specifications for a Social and Technical Environment for Improving Design Process Communication

R.R. Senescu & J.R. Haymaker
Center for Integrated Facility Engineering, Stanford University, Stanford, CA USA

ABSTRACT: The architecture, engineering, and construction (AEC) industry can generate tremendous value by improving design processes. Observed case studies and design literature suggest that processes can improve through collaboration, sharing and understanding (defined here as *Design Process Communication).* Industry has not widely adopted process communication techniques, though other research fields provide points of departure for promoting better communication. Organization Science studies how institutions exchange information and knowledge. Human Computer Interaction, informed by Cognitive Science, explains how computers can aid and supplement human's ability to find and manage information. Process Modeling research shows how to best represent design processes. The paper links this research to develop a specification for a social and technological environment - a Design Process Communication Methodology. The environment is computable, distributed, embedded, modular, personalized, scalable, shared, social, transparent, and usable. The Methodology lays the foundation for improving building design process efficiency and effectiveness from concept to construction documentation.

1 INTRODUCTION

This research aims to derive financial, environmental, and social value from more efficient and effective design processes. 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, Architecture Engineering and Construction (AEC) productivity, actually decreased from 1964 to 2003 (United States Department of Commerce: Bureau of Labor Statistics 2003). As construction project's final value is most influenced by design, the 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 & Levitt's Virtual Design Team (1996) applied this information processing view of the organization to the AEC industry first described by Weber in 1920 (1947) and later adopted by March & Simon (1958) and Galbraith (1977).

Inefficient and ineffective information exchange contributes to construction productivity stagnation. Information flow on AEC projects is inefficient and intermittent (Gallaher et al. 2004). 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).

While 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 (United States Green Building Council 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.

Using case studies, Section 2 explains that collaborating, sharing, and understanding problems inhibit this design process improvement. Collectively, this research defines collaborating, sharing, and understanding, *design processes communication.* This paper extracts findings from Organizational Science, Human Computer Interaction, and Process Modeling research fields. It links these findings to develop a Design Process Communication Methodology that specifies an organizational and technological environment necessary for improving the efficiency and effectiveness of design processes. The paper then describes a tool derived from this methodology, describes metrics for validation, and briefly describes preliminary results from using the methodology.

2 OBSERVED PROBLEM

This section 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, the first author gathered design process information directly and through interviews.

2.1 *Designers struggle to collaborate*

When designing the GSB, researchers identified six discrete stakeholder groups with 29 project goals. The design team evaluated seven mechanical heating/cooling options with respect to numerous stakeholder goals. They divided one building into five different zones and assigned five of the seven mechanical options to these zones. The team created a decision matrix that showed the under floor distribution system is the best choice. However, floor plans communicated to owner representatives showed that in many cases other options prevailed. Predicting how multiple options perform with respect to multiple goals in different contexts required the design team to synthesize information from multiple tools that output multiple measurements.

The result of this informal and inconsistent process caused the owner representatives to “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 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 design 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 impacted 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 struggled to comprehend and manage their information dependencies; they struggled to *collaborate* within the project team.

2.2 *Project teams 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 find a process for conducting 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 & Haymaker 2007). The firm reported using 197 sustainability and 189 structural design tools. A 2008 survey (Senescu & Haymaker 2008) confirmed that project teams struggled to *share* processes across projects.

2.3 *AEC industry struggles 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. Looking to improve the realism of the output, the consultants discovered they could use the process described in (Senescu & 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. Senescu and Haymaker (2008) described how an investment of $2400 could add $32,400 of value annually for just one office.

Yet, individual consultants are not incentivized to invest 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. The AEC industry struggles to *understand* the efficiency and effectiveness of individual design processes and so, AEC professionals cannot make a value proposition for improving processes.

3 RESEARCH TASKS

The previous section describes challenges to: collaborate within projects; share better processes across projects; and understand the best opportunities for investment in improving processes. To address these challenges, the next section aggregates research in other fields to develop a specification for a social and technical environment for design process communication. This paper hypothesizes that by implementing this environment, the AEC industry can improve the efficiency and effectiveness of design processes through better communication. This specification of the Design Process Communication Methodology is the contribution of this paper. Using Agile Software Development (Cohn 2004), the authors use the specification to create a process-based information management web tool, the Process Integration Platform (PIP). The paper discusses preliminary results from using a PIP prototype, which Senescu & Haymaker (2008) describe in detail.

4 POINTS OF DEPARTURE

By aggregating research in Organization Science, Human Computer Interaction, and Process Modeling, the authors develop the Design Process Communication Methodology. Table 1 describes the specifications for this methodology.

The authors choose the research fields in this section, because they each address the obstacles to design process improvement described in Section 2. The authors hypothesize that jointly implemented; the specifications will improve design processes as defined in Section 6. Admittedly, design processes may still improve to some degree even if some specifications are not implemented and expanding the list to include other research fields may in fact improve processes more. The authors selected references in this section that are either highly cited in design theory research and/or provide strong empirical evidence for their claims. The authors stopped looking at new references when the rate of finding unique specifications diminished to near zero.

4.1 *Organization Science*

This paper takes the information processing view of the organization, which was first adopted in AEC by Jin and Levitt's Virtual Design Team (1996) to provide a *transparent* view of business processes.

This section first explains why highly interdependent tasks inhibit process standardization leading to the claim that process documentation should be *embedded*. Research on the Institutions suggests that technology should be *transparent*, *social,* and *shared* to best allocate human capital and creativity. Institutional research on matrix organizations suggests that hierarchically structured information is not suitable in AEC. This research leads to the claim that the representation of information in matrix organizations should be *transparent* and *personalized* to each individual. Finally, Knowledge Management research suggests a value proposition for the emergence, structuring, and sharing of design process knowledge. This research emphasizes the importance of *embedment* of acquisition, *transparency* of structuring; and *socialization of sharing* knowledge.

4.1.1 *Coordination without standardization*

Standardization permits coordination when situations are relatively "stable, repetitive and few enough to permit matching of situations with appropriate rules" (Thompson 1967). In AEC, the International Alliance for Interoperability (IAI) developed Industry Foundation Class (IFC) to standardize data schema for describing buildings (International Alliance for Interoperability). The Georgia Tech Process for Product Modeling (GT-PPM), Integrated Delivery Manuals (IDM), and others also depend on a standard design process (Lee et al. 2007a, Wix 2007). The new capabilities of simulation software, the complex demands of stakeholders, and the global nature of design teams make design processes increasingly complex, dynamic, and performance (not precedence) based. March and Simon (1958) argued at the time that organizations with variable and unpredictable situations prevent process standardization. Instead, coordination must be achieved by "coordination by mutual adjustment," which "involves the transmission of new information during the process of action." Extrapolating, coordination should occur by *embedding* the process in the hour-to-hour work of designers rather than by developing standard coordination methods. This organization science research may explain why such process standards have been relatively unsuccessful in practice and why convergence to a single product model has not emerged in AEC.

4.1.2 *Institution Forming*

Institutionalism research explains relationships between firms and information. Coase (1937) described a model for explaining the development of a firm versus a market. The open source software institution does not fit within Coase's model, and so, Benkler (2002) proposes the alternative peer production model. Benkler claims that this emerging third type of institution "has certain systematic advantages over the other two in identifying and allocating human capital/creativity." The authors seek a design process communication methodology that utilizes these advantages to mimic success in the open source software industry.

Benkler, in describing necessary conditions for "information-production and information exchange chain" in this peer production model, breaks down the "act of communication" into three parts. First, someone must create a "humanly meaningful statement." Second, one must map the statement to a "knowledge map," so its relevance and credibility is *transparent.* Finally, the statement must be *shared*.

Berger & Luckmann's (1967) explanation of the firm provides insight as to how Benkler's peer production model could form. Berger & Luckmann explain that many menial tasks take much effort to complete (e.g. lighting case study in Section 2.3). They argue that "habitualization" is human nature, because it "frees energy" for creative decision making and "opens up a foreground for deliberation and innovation."[1] *Sharing* previous processes allows this creativity through *modular* combination of existing ideas (Hargadon & Bechky 2006) and reduces the burden of redundant activities, so individuals focus on value adding innovation.

In fact, Berger & Luckmann argue that this habitualization of activities is the reason why institutions form. Organizations can invest in technology to perform standard tasks, providing an advantage over the sole practitioner. A larger institution which collectively develops more institutional habits can then focus more on creative endeavors.

For institutions to exist, "there must be a continuing social situation in which the habitualized actions of two or more individuals interlock" (Berger & Luckmann 1967). But what happens when the quantity and diversity of actions and actors is so great that these social institutions do not occur naturally? Individuals in the organization must continuously waste energy on activities that from an institutional perspective, seem habitual, but from the perspective of the individual are unique. Can technology facilitate "social situations" where "individuals interlock" to create reciprocal typification?[2] The authors claim that technology is needed to socialize information exchange and make typification *transparent*, so communities (i.e. institutions) can form around common tasks (i.e. habits).

4.1.3 *Structuring Information for the Matrix*

Programmers in the open-source software movement were simultaneously part of Benkler's peer production model and Coase's more traditional firm. Designers will also exist within a peer production model and the traditional AEC matrix organization.

Three conditions are necessary for an organization to switch to a matrix structure (Davis & Lawrence 1977). Large design companies generally formed matrix organizations, aligned by project, by geography and/or by discipline, but the way in which they stored information remained hierarchical. Companies structured their information according to project, discipline, phase, etc. Just as Davis required that new conditions required a change in structure, the authors analogously argue that changes in the conditions of information storage similarly require a deconstruction of the typical hierarchical structure of information.

First, information now must serve more than one purpose. A building element object such as a window must be used for an architectural rendering, for a daylighting analysis and for an energy analysis. Much effort is exerted to create this window object, and so, it no longer belongs to just one project, but must be used on multiple projects. For the information about the window to be *transparent* across multiple project teams, the references to the information cannot lie in a single folder; transparency requires a non-hierarchical structure. A designer's view of the information should be *personalized* to its function for that designer.

Second, the time it took to find and share information used to be relatively small. But with increased computer power and increased demand to view tradeoffs, information exchange now has a relatively high transaction cost. As was shown in the collaboration problem example, designers struggle to keep information consistent. Thus, the relationship between information should be *transparent.*

4.1.4 *Knowledge Management*

An organization's knowledge is a resource (Grant 1996). In this knowledge-based theory of the firm, the organization is a social community that transforms knowledge into economically rewarded products and services (Grant 1996, Khanna et al. 2005).

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[1] Thompson's standardization refers to collections of information exchanges, whereas Berger & Luckmann's habitualization could involve just the habit of performing a single information exchange repeatedly.

[2] Whereas habitualization refers to recognition of one's own repetitive tasks, typification is the recognition of other's habits. Reciprocal typification is when two people recognize each other's habits (Baumer & Tomlinson 2006).

AEC project teams transform knowledge into designs that they then supply to clients to be built.

Conklin (1996) describes a "project memory system" to define this knowledge and make it available to others. The project memory system is necessary, because organizations lack ability "to represent critical aspects of what they know." Like Conklin, the authors propose an environment that acts as "an evolutionary stepping stone to organizational memory."

Whereas Conklin (1996) generally applies this system to capturing knowledge from meetings, this paper focuses on capturing design process knowledge. The environment tracks information exchanges on a project to deduce knowledge about the design process to be applied on other projects. Conklin's stepping stone from project to organization leads to acquisition of both already existing knowledge and new knowledge.

Once knowledge is acquired, it must be structured. Hansen et al. (2005) describes two aspects of knowledge management: codification and personalization. Codification relies on information technology tools to connect people to reusable explicit knowledge (Will & Levitt 2008). Personalization relies on socialization techniques to link people so they can share tacit knowledge. Information Technology can provide the general context of knowledge and then, point people to individuals or communities that can provide more in depth knowledge. The environment structures design process knowledge through information dependencies and links to people that have even more in depth knowledge about the process.

Knowledge management is not just acquisition and structuring (Kreiner 2002). Will & Levitt (2008) address the additional importance of the future ability of others to find the collected knowledge. Sharing requires both effective pushing and pulling of the collected knowledge. It is this design process knowledge sharing that inhibits better processes from spreading.

Notice that these three components (acquiring, structuring, and sharing) of knowledge management are the same three factors required for Benkler's peer production model. Yet, in Benkler's model, there is minimal if any management. Combining the peer production model with knowledge management research provides guidance for developing an environment for a self-perpetuating acquiring, structuring, and sharing of design process knowledge with minimal if any management.

4.2 *Human Computer Interaction*

The organization science research suggests representing information dependencies is valuable. Human Computer Interaction (HCI) specifies how to facilitate the designer's interaction with the digital representation of the dependencies. Within HCI, the emerging branch of Human-Information Interaction applies Information Foraging Theory, which itself draws on Cognitive Science research (Pirolli 2007). Thus, this section starts with Cognitive Science research, including attempts to use cognitive science for artificial intelligence. The research calls for *personalized* views and recommendations, representations at different *scales,* and *computable modules.* Next, the practical implications of Cognitive Science are discussed with respect to two branches of HCI: human-information interaction and information visualization. These branches provide insight as to how to make the communication environment more *sharable*, *usable*, *scalable,* and *social.*

4.2.1 *Cognitive Science*

Norman (1993) writes "the power of the unaided mind is highly overrated…The real powers come from devising external aids that enhance cognitive abilities." Can a technical environment enhance designer's abilities to collaborate, share, and understand? "Solving a problem simply means representing it so as to make the solution transparent" (Simon 1981). To illustrate, Norman presents the ticktacktoe game (also called "naughts and crosses" and "three in a row"). As a mathematical word problem, finding a solution is very difficult, but represented graphically in the game ticktacktoe, the solution is obvious. Similarly, the graphical representation of information dependencies may greatly impact the ease with which designers collaborate.

Next, Norman presents several representations of airline schedules to demonstrate that the appropriate representation depends on the task. Thus, a communication environment should *personalize* the representation of information according to the user's task.

Personalization also is necessary to make information dependencies comprehensible. To overcome bounded rational (Simon 1969), Minsky (1986) suggests, "It is hard to solve any very complicated problem without giving essentially full attention, at different times, to different sub-problems." The environment must represent information dependencies at different *scales* by embedding more detailed dependencies as sub-processes of more coarse processes. This grouping and ordering of dependencies should depend on personalized tasks. Thus, a manager tasked with managing may see a coarse information dependency graph, whereas a young designer tasked with sizing ductwork would see a very detailed dependency graph.

The above discussion describes human capability and suggests methods for developing HCI tailored to these capabilities. Programmers have also found success developing interactions that mimic the human brain (Pirolli 2007). For example, Vannevar Bush (1945) invented hypertext by explicitly mimicking human associative memory. Minsky's *Society of Mind* provides a model of the human brain that can be applied to developing effective HCI. In the Society of Mind, the mind is made up of subprocesses called *agents*. Each agent performs a process that requires no intelligence, but collectively when joined into a society forms intelligence. The environment should track information relationships and make individual flows of information both *modular* and *computable*. Also, it is important to keep knowledge about the information relationships *embedded* nearby. That is, the environment should link commentary, tool information, and other context directly to the relationships.

Minsky also writes, “We can think of a frame as a network of nodes and relations…The lower levels have many terminals - "slots" that must be filled by specific instances or data." During design, the designer populates the frame with project specific information, but to be reused, it should also be possible treat the relationships as a shell that can later be populated with other project-specific information. In reality, these two conditions are two extremes of a spectrum. The environment must *scale* not only across levels of detail, but also across levels of design certainty. From concept design to construction the certainty of the final product increases.

Winograd & Flores (1987) use Minsky’s idea of the frame to explain how pattern recognition prompts cognition. Whereas Winograd discusses understanding in the context of linguistics, this paper extrapolates to propose that through appropriately framing information dependencies, designers can gain understanding of design processes. As multiple information dependencies and frames of these dependencies develop, patterns emerge, which eventually allow the computer to aid the user in understanding the design processes. The environment should detect patterns between different processes to *personalize* recommendations to the designer.

4.2.2 *Information Interaction and Visualization*

Looking to Pirolli’s (2007) description of information foraging theory, this section seeks to find “how information environments can best be shaped for people.” Information visualization research provides methods to achieve this goal. Information visualization is the “use of computer-supported, interactive, visual representations” of abstract, non-physical data to amplify cognition (Card et al. 1999).

For example, the human eye processes information in two ways. Controlled processing, like reading, “is detailed, serial, low capacity, slow…conscious” (Card et al. 1999). Automatic processing is “superficial, parallel…has high capacity, is fast, is independent of load, unconscious, and characterized by targets ‘popping out’ during search.” Therefore, visualizations to aid search and pattern detection should use features that can be automatically processed. Designers will be able to better draw meaning from information dependency graphs if the graphs use images, fewer nodes, and spatial layouts indicative of topology (Card et al. 1999, Nickerson et al. 2008). Both strategies will make the environment more *usable*. Usability is the user’s time, accuracy, and satisfaction in achieving their goal (Pirolli 2007).

The capabilities of the human eye also influence information scent – the perceived value of choosing a particular path to find information. To promote an accurate and intense scent for the designer to find useful *shared* processes, search results should show the actual information dependency graphs. Also, the environment should track the most useful processes and prioritize these processes in search results.

Heer (2007) extends this finding to show that social groups will reveal more patterns than the same number of individuals. Combining conversation threads with visual data analysis helped people to explore the information broadly and deeply, suggesting a promising opportunity for supporting collaboration in design activities. The environment should allow the community to point to specific locations in the graphs to detect patterns *socially.*

4.3 *Process Modeling*

Process modeling research creates a language for addressing the three communication problems: collaboration, sharing, and understanding. Process model research in AEC can be delineated by different views of the process or by the objectives of the modeling. For example, engineering processes can be viewed through conversion, flow, and value generation (Ballard & Koskela 1998). Ballard suggests that transparency of these views will result in design success from the perspective of that view. Wix (2002) observes that the AEC industry developed generalized process models to support new working methods, identify gaps in product information models, and inform new information models. Process models may also aim to facilitate collaboration, share better practice, or communicate decisions. Though admittedly, process modeling research frequently overlaps multiple objectives, this section first explores process models primarily aimed at improving coordination. The literature claims models should be *embedded*, *distributed*, and *transparent*. Next, the paper discusses process models aimed at improving automation. This research recommends models that are *personalized*, *shared, scalable embedded*, and *computable*.

4.3.1 *Coordination*

Narratives (Haymaker et al. 2004) attempt to overcome the challenges of multi-disciplinary, iterative, and unique design processes. Narratives incorporate Ballard’s information flow view via information dependency arrows and the conversion view by showing the tool used to transform the information. To facilitate coordination Narratives create task-specific

Table 1. Specifications for a Design Process Communication Methodology

Characteristic	Specifications	Reference
Computable	Permit designers to add automation scripts to convert information from one form to another.	Haymaker 2006
	Allow simple computing of information representing a high level of detail.	Minsky 1986
Distributed	Store all project information on a network.	Benkler 2002
	Allow users to find process modules from previous projects.	Berger 1967
	Open process to project team, not just product.	Strong 2006
Embedded	Information relationships must emerge from designer activities.	Thompson 1967
	Track information exchange during the design process.	Grant 1996
	Keep lessons learned about the design process close to the representation of the information.	Minsky 1986
	Represent iterations in dependency arrows.	Haymaker 2004
	Alert designers when iterations are performed with status flags.	Haymaker 2004
	Link between process nodes and actual information files or data.	Lee 2007
Modular	Break processes into segments of information exchanges.	Hargadon 2006
	Allow knowledge to be added with minimal transaction cost.	Benkler 2002
	Automate information exchange at a small, modular level.	Minsky 1986
Personalized	Organize information differently for different people.	Davis 1977
	Associate people with information exchanges.	Hansen 2005
	Represent information differently according to the task being performed.	Norman 1993
	Aid the designer in depicting patterns in design processes.	Winograd 1987
Scalable	Encourage users to reduce the number of nodes per frame by prompting auto-grouping of nodes to generate sub-processes.	Card 1999
	Represent information dependencies at different levels of detail.	Minsky 1986
	Represent information throughout time with different levels of certainty.	Minsky 1986
Shared	Allow searching of processes via paths of information exchanges.	Minsky 1986
	Allow searching across projects.	Minsky 1986
	Show search results as information dependency graphs with images and project descriptions.	Pirolli 2007
	Track the most useful processes and prioritize these processes in search results.	Pirolli 2007
	Prioritize search results according to metrics indicating best practice.	Wix 2007
Social	Form communities around design processes.	Berger 1967
	Allow communication threads to point to specific locations in the graphs.	Heer 2007
Transparent	Represent design processes through information exchanges between designers.	Jin 1996
	Provide metrics around processes that indicate credibility.	Benkler 2002
	Contextualize processes with project information.	Benkler 2002
	Inform designers about the *typical* processes followed by other designers.	Berger 1967
	Organize information according a graphical web of information dependency rather than a hierarchy where information can only lie in one location.	Davis 1977
	Alert designers when information that they used changes.	Davis 1977
	Make the actual data schema transparent	Minsky 1986
	Show designers how much information is dependent on their decisions.	Strong 2006
	Provide metrics that allow processes to be compared.	Eastman 2007
Usable	Include preview images with files.	Card 1999
	Show the relationship in terms of space, not just topology.	Nickerson 2008

views of information flow (consistent with the views suggested by Norman in Section 4.2.1). To be effectively *embedded* in the design process, the process model should accurately reflect the iterative nature of design. Haymaker also expresses the need to facilitate coordination by representing the status of information. That is, process modeling is an *embedded* activity that changes as information changes.

This embedding permits the design process to be quickly and accurately understood by those not involved in the design. The perfect vision of Integrated Practice includes “a world where all communication throughout the process are clear, concise, open, transparent, and trusting: where designers have full understanding of the ramifications of their decisions” (Strong 2006). Thus, the process, not just product models, should be *distributed* to the entire project team. The environment should make *transparent* the information dependent on their decisions.

4.3.2 *Automation*

Understanding how project teams coordinate helps in developing automated information flow, so recent process modeling efforts aim to support both goals. Building on Integrated Practice, the American Institute of Architects (AIA) released a Working Definition – Integrated Project Delivery (IPD). The AIA committee issued supplemental information emphasizing that “Interoperability exists on the human level through transparent business exchanges” (American Institute of Architects 2007). The importance of associating people with information exchange is analogous to Hansen's claim that knowledge must be personalized, not just codified.

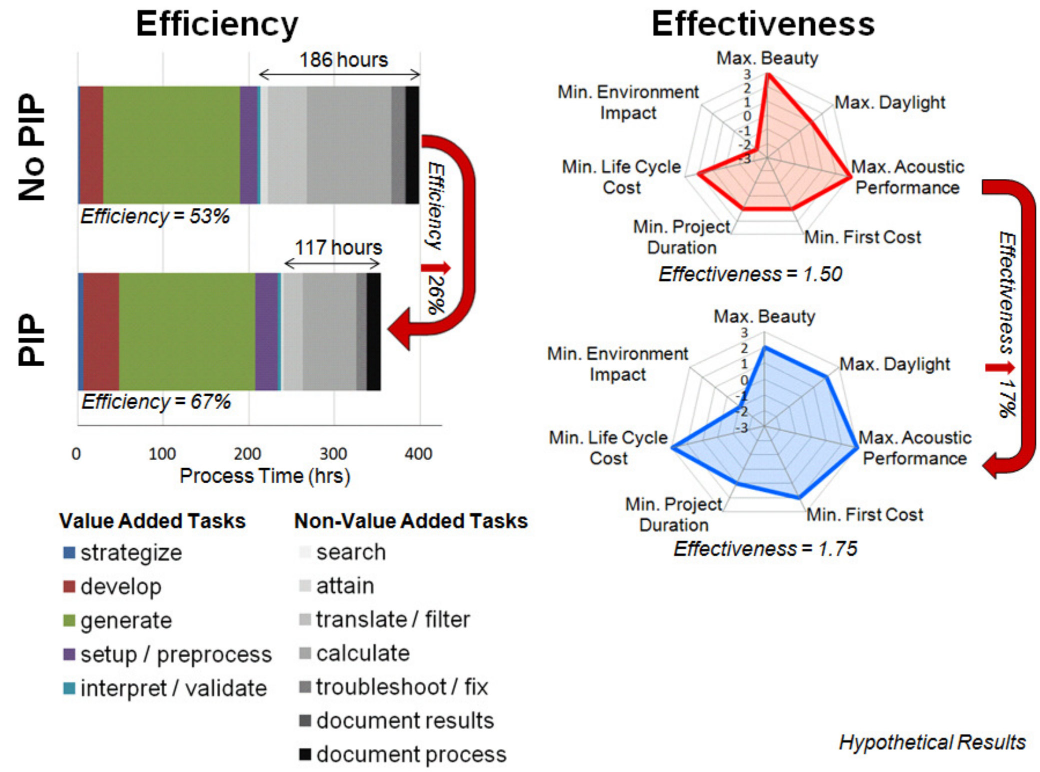
Consistent with the AIA's IPD, IDMs aim to provide a human-readable integrated reference identifying "best practice" design processes and the data schemas and information flows necessary to execute effective model-based design analyses (International Alliance for Interoperability). Similar to Minsky's suggestion for *scale*, IDMs also aim to track information at varying levels of detail. To help identify best practice processes, the environment must promote *sharing* by using metrics to evaluate processes.

IDMs build on the work of Eastman who first proposed the GT-PPM. GT-PPM stresses the importance of process models ability to link to information used in activities, automatically validate information flows, compare different processes, and prompt the derivation of a product model– a formal and structured definition of product information such as IFC's. Lee et al. (2007b) demonstrated the use of GT-PPM to improve product data models. Lee et al. also identified the need for local variation in process; representation of multiple levels of detail; the support of strategic workflow processes; and support for the developmental and evolutionary aspects of product development. They argue that product models must have a closer linkage with workflow.

Whereas Lee et al. share the authors' intuition that process models are critical for design integration, they focus on the use of process models in aiding the development of future product data models. The authors do not attempt to develop such a standard, instead relying on a web of individual interoperability solutions, some of which no doubt will evolve through Lee and Eastman's work. Current process modeling approaches are formulated at an abstract level to define general data exchanges and processes, and have limited value as a project-specific design guidance and management tool. That is, software developers, not designers, use these process models, and they are therefore not intended to be transparent, usable, and sharable from the perspective of the typical designer. This function contrasts with Narrator's focus on designer communication, but is similar to Geometric Narrator, which emphasizes the use of process models to perform modular *computations* on information (Haymaker 2006).

5 DESIGN PROCESS COMMUNICATION METHODOLOGY

This section aggregates the points of departure into specifications for a social and technical environment for design process communication (Table 1). The specifications are organized according to ten characteristics. The specifications summarize the Design Process Communication Methodology, which lays the foundation for managing organizations and developing tools to foster improved communication.



Hypothetical Results

Figure 1. Results from validation studies will use these metrics to measure the impact of the Design Process Communication Methodology on efficiency and effectiveness. These results are hypothetical.

6 VALIDATION METRICS

Senescu & Haymaker (2008) describes the Process Integration Platform (PIP) developed according to the specifications in Table 1. Each specification is linked to a PIP software feature via the Agile Development Method (Cohn 2004). The authors intend to validate the Methodology by measuring the impact of PIP on process efficiency and effectiveness.

By tracking the time spent on value added versus non-value added design tasks, the authors determine the percentage change in design process efficiency. The authors measure effectiveness by evaluating whether the designers meet their design goals. Senescu and Haymaker (2008) explain these metrics in more detail. The authors will run several design charettes (Clayton et al. 1998) to obtain data for these metrics. Figure 1 shows hypothetical results from the planned charettes, which allow the authors to assess the impact of the Design Process Communication Methodology on Efficiency and Effectiveness.

The validation will confirm or challenge the theoretically-founded specifications derived from the points of departure. By tracking users' use of PIP features, the authors will measure the impact of individual specifications on process efficiency and effectiveness and correlate changes in efficiency and effectiveness with improvements in collaborating, sharing, and understanding.

7 PRELIMINARY RESULTS

The authors introduced a prototype of PIP to a multidisciplinary building analysis class at Stanford University. The student group performed multiple analyses to decide between atrium options for the GSB library design. Rather than using e-mail or a common folder directory, the students used the prototype tool shown in Figure 2 as the primary means for collaboration. For example, when the student performing energy analysis, needed to know how much energy would be required for lights, he double clicked on the daylighting analysis node to open a daylighting sub-process and find the information required. The energy analysis student then drew an arrow to the energy analysis node to represent this dependency. He then saved the files he created as a sub-process beneath the energy analysis node. This exercise proves conceptually that it is possible to collaborate via information dependency graphs.

8 CONCLUSION

Designers in AEC struggle to collaborate, share, and understand. To address these challenges, this paper aggregates findings in organizational science, human computer interaction and process modeling research to develop specifications for a social and technical environment, the Design Process Communication

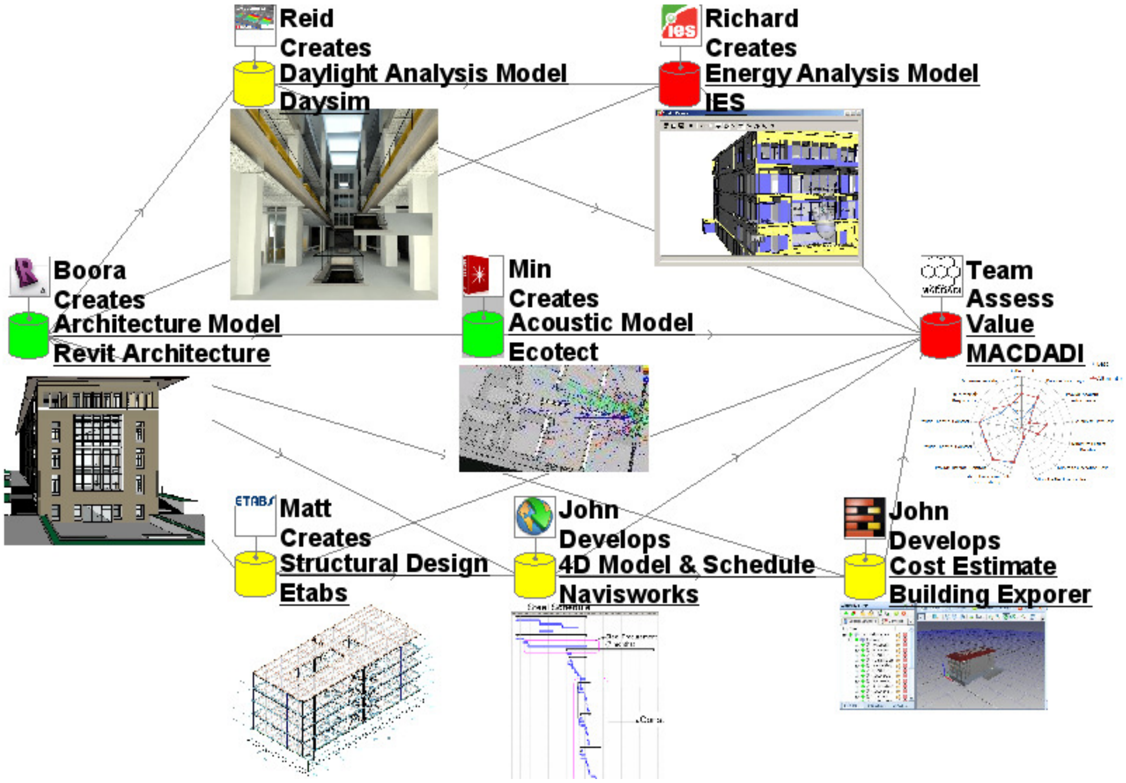


Figure 2: A multi-disciplinary analysis class at Stanford validated the feasibility of using a process-based information management web tool on a design project. This dependency graph shows the highest level view. Each node represents a discipline. Double clicking on the node links the designer to a discipline-specific sub-process with links to information used for design.

Methodology. The paper explained how efficiency and effectiveness metrics are used to evaluate the impact of this methodology on design processes. Preliminary results show the implementation of the social and technical environment is possible. Future research will use the metrics presented to measure impact. The findings will either confirm or challenge the applicability of this other research to the design process communication problems in AEC.

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