Executive Summary

During the conceptual design phase of a construction project, the building owners make major decisions that have life-cycle influences on their capital facilities. Often without technical experience in building construction, the owners rely on the construction managers, or owner representatives, and their technical skills to provide analytical support during the decision processes. This seed proposal is motivated by two recent examples in which the owners were unaware of, and subsequently dismayed by, the resulting cost and risk implications of two seemingly discipline-specific adjustments. Specifically, the owner team in our first case study approved architectural adjustments without evaluating the ramifications for structural rework, mechanical coordination, and the life-cycle operating costs. In the second case, the technical team was not able to quantify the ripple effects of a spatial adjustment in an ad hoc situation. Analyzing current best practices, we find that the lack of an easily understandable summary view of the decision parameters and the discipline-specific reporting mechanism have hindered an objective interdisciplinary evaluation of project alternatives. There is a need to develop visualization tools that support decision-making across different architecture/engineering/construction (AEC) domains.

Taking the interactive workspace (iRoom) environment and our case studies as focuses, this research will develop appropriate decision-support views to balance the qualitative concepts with quantitative assessments: Qualitatively, we propose to formalize implicit knowledge and relationships with which decision makers would evaluate the impacts of architectural alternatives across different disciplines; Whereas quantitatively, we will develop assessment mechanisms with which decision makers would assess the coordination, rework, and life-cycle impacts of cost and risk from structural, mechanical, and construction domains. We envision the quantitative and qualitative balance will translate technical decision parameters to more easily understandable costs and risks. Thus, we will partner with CIFE members to test whether iRoom-enabled decision-support views will improve the project team’s ability to uncover embedded risks and the client’s breadth of understanding. During the funding period, we anticipate to develop various application scenarios for our iRoom decision-support views based on the two retrospective case studies and the CIFE Flagship project, while creating a formalized foundation for future research on interdisciplinary decision supports.

The engineering/business problem that motivates the proposed research

The building owners and end-users, or the clients in general, respond more positively to visual materials (e.g., architectural rendering, computer animations), cost amounts, and other daily terms (e.g., temperature differences, material choice), while they are less attentive to the technicalities in construction (e.g., penetration of building components into structural elements, mechanical system efficiency, design coordination). Hence, the success or failure resulting from an early project decision depends on both the ability and the due diligence of the technical team to uncover potential ripple consequences prior to the client’s decision. In today’s best practices, the technical project team utilizes sophisticated visualization tools, analytical software, and simulation programs to provide decision support within specific domains. For interdisciplinary issues such as coordination costs, rework delay, and life-cycle costs, today’s best professionals count on their technical experiences and abilities to apply their interpersonal or moderating skills to inform and guide their clients.

The limitations of today’s best practices are that the clients count on their mental power to synthesize decision factors as their consultants swamp them with discipline-specific project factors. At the same time, the project teams count on their moderating skills to elevate client’s inputs from a specific discipline to the total project view. As the following examples illustrate, today’s decisions often focus on a micro-level of domain-specific interests. The ad hoc means of focusing or relating information in the decision process can adversely impact a project throughout its life-cycle.
Example One: Deciding between the skylight and the strip-window alternatives in a foyer space

During the conceptual design phase of a new auditorium building, the management team in the owner’s organization held a meeting to review the project design. The owner representative gathered project updates from various consultants (structural reports from the structural engineers, conceptual cost estimates from the construction manager, and mechanical concerns from the building systems consultants) and presented the design progress along with the architect, who proposed two alternatives (skylight vs. strip-windows) to the owners. Given the many binders and reports from each of the aforementioned engineering and construction disciplines, the owners were not able to mentally relate all the information into decision factors. However, because the owners understood the visually appealing architectural posters and rendered animations, the major portion of the meeting focused on the discussion of spatial configurations and architectural features.

Rather than choosing between one of the two architectural features, the owners speculated about incorporating both skylight and strip-windows in the design. The team present estimated the difference in cost, based on the component cost information from the available proposals prepared for both the skylight and strip-window cases. The owners found the cost difference acceptable, and the project team proceeded with the hybrid design.

Figure 1 shows the product of the final design which incorporates both skylight and strip-windows features.

As the project evolved, the hybrid design revoked several primary assumptions made by the mechanical and structural designers. The additional architectural features brought about higher thermal loads and called for larger duct sections to be fitted in a tighter interstitial space. Since the additional budget approved only accounted for the direct cost of additional material and installation, the structural engineers had to coordinate with the cost estimators to come up with less costly structural solutions to compensate for the additional structural spans imposed by the hybrid design. As a result, the team sought a prefabricated structural system, which was more economical but deeper in size, and thus further reduced the interstitial space because there was a height limit on the building envelope. During construction, the MEP coordination challenge was tremendous. In spite of additional coordination, the structural-mechanical interference had caused a change order and rework during field installation. The redesign and reorder of shallower, but wider and thus less efficient, duct sections delayed the project for a week. In terms of the life-cycle costs, the higher thermal loads and the less efficient building systems adversely increased the operation costs and energy waste through the facility’s total life span.

In a nutshell, the owners were not aware of the “total cost”, the associated risks of coordination and rework, or the questions they could have asked prior to making a decision. The meeting fell into a microscopic discussion of architectural issues since the owners did not have the same level of understanding about the technical issues. The project team relied on discipline-focused tools that were not able to uncover interdisciplinary or facility management impacts. These practical and engineering problems have motivated our proposed research into the means of providing a more systematic approach to evaluating conceptual alternatives and a means of focusing the client’s attention on the total project view.

1 The example is slightly modified from the Helsinki University of Technology’s HUT-600 Auditorium Case Study (Kam et. al. 2002).
Example Two: Evaluating a change of spatial configurations in a laboratory complex

During the schematic design phase of a laboratory complex, the architectural design team briefed the Director of Research, the ultimate decision-maker representing the end-users, about the design progress. The Director suddenly came up with an idea of swapping the laboratory spaces with the office spaces. Rather than centralizing the office spaces and encouraging interaction in the core of the building, the Director strongly preferred reconfiguring the office spaces to take full advantage of the exterior views. The architects and owner representatives present foresaw potential ripple consequences that this decision would have for other consultants and their work in place. In spite of the verbal explanations and the skepticism expressed by the team present, the Director did not find any solid compelling evidence against his strongly-held idea that the domain-specific change would only affect the spatial configurations. Figure 2 shows the reconfigured plan in which laboratory spaces are in the core.

As in the case of the first example, the decision to swap the spatial configuration translated into rework across all disciplines, extra coordination, schedule delays, and system inefficiencies, all of which adversely affected the project schedule and quality, while jeopardizing the life-cycle performance and costs of the capital facility.

Summary of engineering/business problems

<table>
<thead>
<tr>
<th>Case Studies</th>
<th>From the two case studies we find that in project meetings during the conceptual design phase, the clients often:</th>
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<tbody>
<tr>
<td></td>
<td>(1) focus on a &quot;Micro&quot; discussion</td>
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<tr>
<td><strong>Backgrounds/Reasons</strong></td>
<td>The clients responded better to graphics, costs, and other non-technical terms. Hence, they focused on spatial relationships, program configurations, rather than structural or MEP impacts, or life-cycle concerns</td>
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<tr>
<td><strong>Results in Case Studies</strong></td>
<td>Lost the &quot;Macro&quot; picture (e.g., unable to address life-cycle costs or interdisciplinary impacts)</td>
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<td><strong>Clients</strong></td>
<td>They do not possess A/E/C professional background</td>
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<td><strong>Today’s Best Practices</strong></td>
<td>(1) The clients hire owner representatives to lead experienced consultants</td>
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<tr>
<td><strong>Limitations of Today’s Best Practices</strong></td>
<td>Loss of a global focus on decision factors: Not all decision-makers are on the same level of understanding</td>
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Table 1 summarizes the limitations of current decision processes to evaluate project alternatives.
Analyzing the participants’ background, the content, and the processes of clients’ decision-making based on the above examples, we have categorized contributing problems as follows:

- **Loss of a global focus on decision factors:** Among the decision-makers, there is a lack of common understanding about the decision factors. The information scattered in the many reports, posters, and binders often distract the meeting participants from the central focus.

- **Ad hoc means to evaluate conceptual alternatives:** There are no decision-support tools or mechanisms to inform the clients about the “total bill” or the risks that come with the project alternatives. At the same time, the clients often raise “what-if” questions that prompt the technical team to come up with impromptu decision factors.

- **Microscopic domain-specific discussions:** Clients are more attentive to comment on easily understandable information. This often leads to a micro-focus of discussion. Furthermore, not all disciplines are present in a decision meeting. As a result, architectural factors and discussions tend to dominate the clients’ decision making processes.

**The proposed research effort and methodology**

Previous CIFE researcher Kathleen Liston (2001) studied the construction information visualization in the interactive workspace (iRoom) and evaluated construction information technology with a new set of metrics (descriptive, evaluative, explanatory, and predictive tasks). Liston’s work demonstrated that with appropriate highlight techniques the interactive workspace reduced the time for the decision-makers to understand the parameters (the descriptive tasks), and in turn spend more time in evaluative and predictive tasks. Our research will build upon this concept to focus on the decision-makers’ breadth of understanding, while extending Liston’s work to test both the content and the representation of decision factors. Rather than integrating available project data (e.g., 4D models and schedules), we search for the hidden interrelated relationships (e.g., potential impacts on MEP, structure, and coordination) and represent them to the decision makers through costs and risks outputs.

In the search for the ways to represent implicit knowledge and formalize the rationales of a technical profession, previous CIFE researcher Sheryl Staub-French (2002) documented her ontology for relating features and activities to support cost estimating. Staub-French formalized cost estimating knowledge about “how and when the building design influences construction costs”. This research builds upon this formalization and ontology development approach, while extending attention to “how the design alternative influences design rework costs, coordination costs, construction costs, and operation costs”. In particular, we recognize the uncertainty of “costs” being the only evaluation metric and, thus, intend to better account for the uncertainties and their occurrence likelihood with a second evaluation metric—“risks”.

This research aims at improving the decision processes to evaluate conceptual alternatives. To address the dynamic nature during early project phases and to ensure extensibility of our work, we will focus on the methodologies and visual catalysts for evaluating and assessing decision alternatives. Rather than pursuing an artificial intelligence-based solution that would automatically generate suggestions based on an intelligent product model, our prime objective is to develop appropriate decision-support views to balance the many interdisciplinary decision factors. Based on the two aforementioned case studies and the CIFE Flagship project, the proposed work will utilize the iRoom environment to simultaneously inform the decision makers about macroscopic and microscopic issues, as well as qualitative and quantitative factors.
Develop "executive summary" view with the iRoom through:
Micro (e.g., component life cycle cost) vs. Macro Focuses (e.g., total project cost)
Qualitative (e.g., architectural features) vs. Quantitative factors (e.g., cost and risk)

<table>
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<tr>
<th>The Proposed Research</th>
<th>The Research Promotes Better Decision-Making by</th>
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<tr>
<td>Qualitative: develop an ontology to assist the project teams in evaluating architectural features, uncovering and communicating the interdisciplinary impacts</td>
<td>A more systematic investigation of interdisciplinary impacts</td>
</tr>
<tr>
<td>Quantitative: develop mechanisms to assess interdisciplinary impacts through costs and risks</td>
<td>Communicating interdisciplinary impacts with more appealing and easily understandable terminologies</td>
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Table 2 introduces the key elements in this proposed research.

Extending the interactive workspace visualization technology <Visualization and Representation>:
To address the lack of common understanding of the decision factors among the decision-makers, we intend to extend the interactive workspace (iRoom) technologies. With the interlinked displays, the decision makers can compare an alternative against the benchmark case in a “project dashboard” view. We envision that the iRoom’s integrated displays simultaneously balance “macro views” and “micro views” in order to focus the decision-makers’ attention on the interdisciplinary decision factors. Two iRoom displays can show the “macro views” where qualitative parameters (such as architectural features and spatial configurations) and quantitative parameters (such as schedule, costs and risks) can be shown separately but concurrently. Thus the “macro views” will also serve as the “executive summary” view or the “project dashboard” view. The middle smartboard displays the “micro view”, which will assist the stakeholders present in dynamically evaluating, assessing, predicting, and finally, updating the quantitative values expressed in the “macro views”. We divide our qualitative and quantitative approaches as follow:

1. **Qualitative Evaluation: Formalization of ripple relationships into a computer ontology**
   As the ad hoc means to assess impromptu project alternatives often lead to unsatisfactory outcomes, we propose to capture, and subsequently develop, an ontology to represent the implicit relationships between an architectural alternative and its impacts. Specifically, we will perform two retrospective studies to capture the experiences and feedback from the affected structural engineers, building systems consultants, and facility maintenance teams. We will identify the relationships between the architectural adjustments and their ripple consequences. The ontology and the uncovering mechanism will empower the decision-makers to identify potential areas of conflicts for quantitative assessment or prediction. We will incorporate risk assessment of interdisciplinary impacts based on their impact level and occurrence likelihood (e.g., reducing interstitial clearance has high risk of extra-coordination and rework).

2. **Quantitative Assessment: Costs and risks analyses**
   Since the clients are not trained as design or construction professionals, we should communicate the ripple effects in non-technical terms. Hence, we propose to use costs and risks as the communication vehicles. We hope to complement the aesthetic and spatial discussions, which often drive the decision-making processes, with the alternative’s embedded effects as represented by costs and risks. With the suggested ripple consequences resulting from the above qualitative evaluation, we will take readily available tools (e.g., VITE’s SimVision, Granlund’s BSLCC) and concepts (e.g., Total Economic Impact approach, Rasmus (1998)) to estimate various costs (e.g., schedule delay cost, rework cost, extra-coordination cost, and life-cycle cost). During the early project phases, the uncertainties are high and direct cost estimation alone may not be the most effective communication tools.
In support of CIFE goals

This research supports CIFE’s Flagship project and reinforces the following CIFE goals as described in the “2002 Call for Seed Proposal”:

1. “Special acknowledgement for extending display and visualization technologies ‘iRoom’”
2. “Visualization of related project data from different discipline perspectives (design functions, physical forms, construction processes, budget, cost, schedule, safety, contract and specification)”
3. “User interfaces for different stakeholders ‘Project Dashboard’”
4. “Methods to identify, manage, and minimize the direct costs of facility management”

Testing methodology and milestone

During the 2002-03 academic year, the proposed research will focus on internal development of an evaluative ontology and the appropriate iRoom visualization supports for decision making among conceptual alternatives. Testing with retrospective case studies and demonstration at CIFE events will be our prime focus. Through our prototype, documentation (e.g., the “Guidelines for Decision-Support Applications in the iRoom”), and dissemination, we will formalize a foundation for future research on decision supports for interdisciplinary collaboration. By the end of each academic quarter, we envision the following corresponding deliverables:

<table>
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<tr>
<th>December, 2002</th>
<th>Evaluation with Ontology</th>
<th>Assessment with Costs and Risks</th>
<th>Visualization with iRoom</th>
<th>Dissemination of Results</th>
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<tr>
<td></td>
<td>Identify Relationships based on Cases, Research, and Interviews</td>
<td>Background Research on Methodologies, Evaluate Available Costs and Risks Model</td>
<td>Conclude Linkage Plans, Design Macro and Micro Views</td>
<td>Project Website</td>
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<tr>
<td>March, 2003</td>
<td>Based on Motivating Case Studies, Develop Appropriate Visualization Views Integrating Qualitative Views, Evaluation Mechanism, Costs and Risks Assessment, and Decision Supports</td>
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<td>First Draft of “Guidelines for Decision-Support Applications in the iRoom”</td>
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<tr>
<td>June, 2003</td>
<td>Iterative Refinement and Redevelopment of Appropriate Visualization Views Based on Internal Comments</td>
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<td></td>
<td>Live Demonstration of Retrospective Cases at 320 Seminar and 243 Class</td>
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<tr>
<td>September, 2003</td>
<td>Iterative Refinement and Redevelopment of Appropriate Visualization Views Based on both Internal and External Comments</td>
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<td></td>
<td>Presentation at CIFE Summer Program</td>
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</table>

Table 3 highlights the focuses and anticipated deliverables by the end of each quarter.

Involvement of CIFE members

CIFE’s Finnish Partners have expressed interests in collaborating with the proposed research. In particular, Olof Granlund Oy is benchmarking a “Client Reporting” model. Because Granlund is keenly looking into means to leverage this client-oriented concept through information technologies and the Interactive Workspace, it has shared its report materials and approaches with us. In submitting a global partnership research funding proposal to the Finnish National Technology Agency in Finland, Granlund identified us as collaborators in areas that are aligned with this proposal’s scope. Meanwhile, Senate Properties—the national property owner and real estate developer in Finland, has proposed to contribute both its expert knowledge and an upcoming capital project for the University of Joensuu, Finland as a test case for our research in decision-making with the Interactive Workspace environment. Both the CIFE Flagship and the Senate Properties projects may be good validating opportunities for our proposed work.
**Anticipated results and potential impact on practice**

The award of this seed proposal will allow us to provide concrete evidence of evaluative mechanisms and an interdisciplinary approach for decision supports among project alternatives. We anticipate the “Guidelines for Decision-Support Applications in the iRoom” and the prototype will induce the industry to rethink the discipline-based approaches to evaluating impromptu project alternatives.

**Anticipated major risks that must be overcome during the course of the research**

In the pursuit of a generalized formalization of interdisciplinary relationships, this research needs to account for the dynamic nature during early design phases. This research will not require a product modeling approach because such strict imposition may risk the extensibility of the research results. We anticipate our work to uncover interdisciplinary ripple effects regardless of the input format (e.g., rough 3D models, 2D architectural rendered posters, or sample photos). Therefore, this research responds to the changing contexts and evolving goals set by the decision-makers (e.g., to allow real-time application of our prototype when the research director, in the second motivating example, asked a what-if question). We will focus on the methodologies and visual catalysts for evaluation rather than on an artificial intelligence-based solution that would automatically generate suggestions based on an intelligent product model.

**Plans for obtaining external continuing funding**

Successful award of this seed proposal will allow us to carry out and test our intuitive ideas. We can develop prototype, present demonstration, and document our results. These tangible outputs will allow us to continue our partnership with our Finnish collaborators and pursue for continuing funding from abroad (e.g., TEKES) and within the U.S. (e.g., the National Science Foundation).

**References**


