An Integrated Conceptual Design Process for Energy, Thermal Comfort, and Daylighting

Prepared for:
Jim Sweeney
Director of the Precourt Institute for Energy Efficiency;
Professor of Management Science and Engineering,
Stanford University

Principal Investigator:
John Haymaker, PhD, AIA, LEED AP
Assistant Professor

Research Staff:
Benjamin Welle, P.E., C.E.M., LEED AP
PhD Student
Center for Integrated Facility Engineering (CIFE)

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The life-cycle energy, thermal comfort, and daylighting performance of buildings is substantially determined in the early stages of the design process. Performance-based analysis methods supported by product models have little opportunity to inform these early stage design decisions because current tools and processes do not support the rapid generation and analysis of alternatives. The goal of this research is to reduce the time required to complete such design iterations. We anticipate that this will allow design teams to formally investigate the energy, thermal comfort, and daylighting performance of many more alternatives during the conceptual design phase leading to improved built environments. To this end, we propose to (1) develop a framework to measure the effectiveness of multidisciplinary analysis (MDA) methodologies using time as the unit of analysis; (2) identify the critical conceptual design parameters and parametric relationships for energy, thermal comfort, and daylighting; (3) implement methods and technologies including building information modeling (BIM), parametric modeling, and process integration and design optimization (PIDO) to automate discipline analysis and process integration for energy, daylighting, and CFD simulation using EnergyPlus, Radiance, and Fluent, respectively; and (4) measure the effectiveness of these new methodologies using the described framework.
2.1 OBSERVED PROBLEM

The vast majority of buildings today suffer from inadequate performance, such as excessive energy consumption, thermal comfort issues, and insufficient daylighting. These deficiencies are often the result of an inability of the design team to consider a wide variety of design options for all these criteria in an integrated and systematic way. Budget, schedule, and technology constraints mean that less than a handful of design options are typically modeled and analyzed today. Advancements in computer-based Building Information Modeling (BIM) and analysis methods now allow architects and engineers to simulate building performance in a virtual environment. However, the potential of this technology to inform the early stages of the design process has not been fully realized because current tools and processes do not support the rapid generation and evaluation of alternatives.

The goal of this research is to identify and test a methodology that reduces the time required for architects and multidisciplinary engineers to complete design iterations that evaluate sustainable design goals in the areas of energy, thermal comfort, and daylighting. This methodology will leverage the technical capabilities of BIM, rapidly developing building analysis tools, and other relevant model-based design and communication applications. Following is our diagnosis of the problem to be addressed by this research.

2.1.1 Process Analysis

We recently asked 50 engineers at a leading Building Engineering firm, how they spent their time during the conceptual design process. Figure 1 shows the result of this survey. This preliminary research shows that architects and engineers spend the majority of their time managing design information (58%) and relatively less time specifying (6%) the processes to construct information, and executing (36%) the construction of this information. In all, it takes architects and engineers over one month to generate and analyze a design option using current building analysis models and, typically, less than three such iterations are completed during the conceptual design phase (Flager and Haymaker, 2007). These shortcomings are due to tool, process, and designer limitations.
The optimized design of building energy, thermal comfort, and daylighting performance ideally requires an iterative design process that currently does not take place for several reasons. First, building analysis tools require design parameters that are not captured within traditional architectural and mechanical design tools. Second, designers have difficulties generating multiple design options and exploring solution spaces. Third, a lack of interoperability between building design and building analysis tools (e.g. for architecture to energy) significantly hinders the ability to leverage existing information. Finally, designers struggle to integrate the results of analysis tools and optimize the related parameters to meet their particular design goals. Figure 2 illustrates some of these issues. These four areas are discussed in further detail in the following section.

**Figure 2**

Current Model-Based Building Analysis Deficiencies

![Diagram showing energy simulation, daylighting simulation, and thermal comfort simulation applications with BIM model.](image)

**Figure 2**: (A) Data transfer capabilities between BIM models and building analysis tools are typically restricted to geometric information, and even that design information is not transferred efficiently. (B) Additionally, there is a lack of methods to evaluate trade-offs and optimize the relevant design parameters between disparate building analysis applications.

2.2 **THEORETICAL POINTS OF DEPARTURE**

In this section we first describe the fundamental points of departure for our research and their limitations.

2.2.1 **Building Information Modeling**

Building information modeling (BIM) is a data-rich, object-based, intelligent digital representation of a facility which includes not only 3D geometric models (and, therefore are capable of directly generating 2D and 3D drawings), but also specific information on a wide range of building elements and systems.
associated with a building (e.g., wall constructions, material properties, spaces and thermal zones, heating, ventilating, and air conditioning (HVAC) systems, geospatial information, space loads, etc.). This information can be used by other building analysis purposes, such as cost calculation, building code checking, clash detection, and, for the purposes of the proposed research, energy/thermal comfort simulation, and daylighting. Though the functionality of the most common BIMs (Autodesk Revit, Bentley Architecture, Graphisoft’s ArchiCAD) have progressed significantly in the past few years, much of the potential of BIM remains largely untapped. Further work is needed to determine if the appropriate design information for use in energy, thermal comfort, and daylighting analyses can be captured within a building information model.

### 2.2.2 IFC and XML

Industry Foundation Classes (IFC) and Extensible Markup Language (XML) are task and schema specifications that provide standard ways to define information like that contained in BIM. IFC is an object-oriented data model developed by the International Alliance for Interoperability (IAI) used to describe the relationships and properties of building specific objects. To date, its industry implementation is limited due to gaps in capturing the entire extent of AEC information (it is currently limited to geometric information) and the lack of software systems that support it.

XML is a set of rules for designing text formats to structure information. Several industry-specific sets of rules of XML-based schemas are currently being developed for the AEC industry (aecXML, green building XML (gbXML), ecoXML, virtual environment XML (veXML)), but none have emerged to gain wide industry acceptance.

Both IFC and XML create a common language for transferring BIM information between different BIM and building analyses applications while maintaining the meaning of different pieces of information in the transfer. This reduces the need of remodeling the same building in each different application. It also adds transparency to the process. A wide variety of data specific formats are available to enable interoperability which can be customized to process specific needs, but more research is needed to establish how to apply these standards to conceptual building design for energy, thermal comfort, and daylighting.

### 2.2.3 Building Analysis Tools

Building Analysis Tools for the simulation and analysis of energy, thermal comfort, and daylighting have varying degrees of functionality and interoperability with the IFC and XML schemas. Though a wide range of building analysis tools are used in industry to meet specific simulation needs, three of the most advanced and widely used simulation engines on the market today for energy, daylighting, and thermal comfort (or computational fluid dynamics (CFD)), are EnergyPlus, Radiance, and Fluent, respectively. These applications require a wide range of design parameters to be specified by the user, many of which can be captured within a BIM. Further research is needed to identify the required design parameters of these specific applications that may be captured in IFC and XML format, their current ability to do so, and the highest priority interoperability enhancements for the purposes of sustainable building design.

### 2.2.4 Process Integration and Design Optimization

Process Integration and Design Optimization (PIDO) is an emerging line of software products developed in aerospace design that aims to give users the ability to integrate processes that utilize multiple digital design and analysis tools. These products allow software tools to be “wrapped” and published on a computing networks. This allows disciplines to keep ownership of their codes, maintain and upgrade them, and serve them from their preferred computing platform. PIDO tools also provide a
graphical environment which permits users to select published components and graphically link their inputs and outputs as required to create an integrated multidisciplinary analysis (MDA) model. Among limitations of PIDO tools are the lack of support of various process components and a narrow problem focus that does not explicitly address multidisciplinary teams’ communication and coordination issues. Very little work has been done to date to test the effectiveness of these frameworks in the AEC domain, and whether or not the PIDO framework can effectively capture, analyze, and optimize the necessary design parameters of the specific building analysis tools listed above for energy, thermal comfort, and daylighting.

2.2.5 Process Models

Narratives [Haymaker, J., et. al. (2004)] are a process modeling language to describe and communicate the design process using an acyclic graph structure. Each node in the graph corresponds to a defined information representation, and the reasoning process which operates on inputs to produce this output. Narratives help AEC professionals communicate multidisciplinary design processes and the information models used in these processes. However, Narratives do not explicitly facilitate the exchange or coordination of information for the described process. While PIDO assists in process integration and optimization, Narratives assist in communication.

Information Delivery Manuals (IDMs) are an integral component of the International Alliance for Interoperability’s (IAI) buildingSMART initiative and Industry Foundation Classes (IFC) development effort for the advancement of building information modeling (BIM) functionality. The purpose of IDMs is to provide a human-readable integrated reference identifying “best practice” design processes and the information flows necessary to execute effective model-based design analyses, and specify the required data schemas to support this process. However, current IDMs are formulated at an abstract level to define general data exchanges, processes, and design team requirements, and have limited value as a project-specific design guidance and management tool. More comprehensive process maps are needed that allow for the inclusion of a project’s participants (such as owners, project managers, and community groups), goals, preferences, schedule, budget, and building delivery process, providing design guidance and management for the required communication and data exchange processes and iteration loops.

2.3 RESEARCH QUESTIONS

The following research questions will be addressed by our research:

1. What processes and information are required for energy, thermal comfort, and daylighting performance-based conceptual building design?

2. What technologies can best manage these processes and information to achieve the highest performance designs?

2.4 RESEARCH METHODS

Our research methods can be broken down into two concurrent parts, one dealing with problem definition and strategy, and the second dealing with implementation and testing. Part one consists of five stages: (1) development of a framework to measure MDA process effectiveness, (2) evaluation of current MDA processes used by leading multidisciplinary teams, (3) research on the potential of current building information models to capture the necessary design parameters, (4) exploration of data schema interoperability between building information models and several popular building analysis tools for
energy, thermal comfort, and daylighting, and (5) the proposal of a new MDA process for integrated
design. Part two, implementation and testing, consists of three stages: (1) develop a PIDO platform for
energy, daylighting, and CFD simulation to support the new MDA process and (2) conduct multiple case
studies incorporating the PIDO process into real project MDA processes, and (3) measure the
effectiveness of each of our proposed interventions to current practice. We describe all of the stages in
detail below.

2.4.1 Development of Process Analysis Framework

Relying on work done within the areas of systems engineering, workflow management and AEC we will
continue to expand our framework for the documentation and measurement of design process
effectiveness. The framework is needed to precisely characterize the processes executed and challenges
faced by teams of multidisciplinary professionals attempting MDA. We will use this framework to assess
the MDA processes applied in practice today, and those we will implement as part of this proposal. The
results of these analyses will help us understand how the PIDO methodologies we implement impact
practice, and identify areas for future improvement.

2.4.2 Evaluation of Current MDA Processes

We will analyze three current MDA processes by leading mechanical design firms such as Taylor
Engineering and Arup. First, the Taylor Engineering MDA process will be evaluated in the context of the
Stanford Green Dorm Project. The Green Dorm is an ideal case study for this research since design goals
in energy, thermal comfort, and daylighting will all be considered. We will work close with Allan Daly, a
principal at Taylor and the current project manager on the Green Dorm project. A second MDA process
evaluation will then be implemented on one of the several Stanford University/Arup projects slated to
begin the feasibility/conceptual design phase later next year. A third case study is to be determined.

For each of these cases, we will document design team methodologies for executing energy, daylighting,
and thermal comfort analyses, whether these simulations are integrated or automated in any way, the time
requirements for model-based analysis, specification, coordination, and information management, and the
effectiveness and value of these processes.

We will also use these cases to analyze the required design parameters and exchange requirements for
effective integrated thermal design, and the appropriate coordination, feedback, and decision-making
loops that must take place to ensure the project meets its sustainable design goals.

We will test the generality of these observations in several ways. First, Benjamin Welle is currently
working with domain experts as part of the Open Geospatial Consortium (OGC) AECOO Testbed
(described in more detail later), and is the lead on a project to identify early design exchange requirements
for energy simulation. Second, we will work with the energy consulting firm KEMA/Xenergy, a leader in
both existing building and new construction building thermal performance, on similar issues. Benjamin
Welle, the research staff for this project, worked as an energy engineer at KEMA/Xenergy for 5 years.
Finally, we will evaluate current published research and design principals in these three areas.

2.4.3 Research Potential of BIM to Capture the Necessary Design Parameters

We will evaluate the potential of the four most popular building information models, Autodesk Revit,
Bentley Architecture, Graphisoft’s ArchiCAD, and Nemetschek Vectorworks to capture and utilize the
appropriate design parameters needed to meet energy, thermal comfort, and daylighting sustainable
design goals.
This work will primarily be executed through Benjamin Welle’s involvement in the OGC AECOO Testbed (discussed on page 9). Benjamin is working with the CAD vendors to identify test models of the GSA headquarters building in Washington DC for demonstration purposes of the Testbed. In addition to the Testbed, we will work closely with the United States General Services Administration’s (GSA) Office of the Chief Architect’s (OCA) National 3D-4D-BIM Program on this task. Benjamin Welle is currently a CIFE Visiting Fellow at the GSA OCA’s National 3D-4D-BIM Program, and is in the process of developing the GSA’s BIM Guide Series 05-Energy Performance and Operations. He is working with national and international AE firms and organizations, and other BIM industry leaders in this effort. Unparalleled access to case studies, BIM software vendors, and GSA project team members is available to our project team through our relationship with the OCA’s 3D-4D-BIM Program Manager, Peggy Ho, a current Stanford CIFE PhD student. The result of this task will be to provide revised information requirements to BIM vendors and have vendor implementation of those requirements by early 2009.

2.4.4 Exploration of BIM and Analysis Tool Interoperability

The project involvement listed above will be used to identify the existing structure and format of IFC and XML information that is exchanged on the selected projects. This research will be coupled with literature review of data schemas currently researched in the AEC and parallel industries. This information will be studied to recommend an existing or infer a new data schema to facilitate interoperability. We will then specify the format and structure of information to be exchanged for the selected projects, establishing information transfer protocols between building information models and building analysis tools for energy, thermal comfort, and daylighting.

2.4.5 Development and Documentation of Proposed MDA Processes

The results of 2.4.2, 2.4.3, and 2.4.4 will be processed and synthesized to create a best practice MDA process for the integrated design of energy, daylighting, and thermal comfort performance. The process models in Section 2.2.5 will be used to document this new process. The remaining research tasks, 2.4.6, 2.4.7, and 2.4.8 will be used to execute and test this new process.

2.4.6 Develop PIDO Platform for Energy, Daylighting, and CFD Simulation

We will implement this new process in our chosen PIDO software platform. This implementation will require research into design methodologies and programming scripts to automate the data extraction from the created building information models for use within the selected building analysis software tools and to integrate that data.

Parametric modeling processes will enable the designer to specify a range of design solutions to analyze. The performance of these design solutions will then be able to be evaluated through an energy, daylighting, and CFD simulation in a rapid and integrated manner. Different types of optimization algorithms (genetic algorithms, gradient optimizers, hybrid optimizers) will be utilized and evaluated in the PIDO software for thermal performance design. We hypothesize that such process integration will enable designers to quickly understand the multidisciplinary performance trade-offs of a particular design, and to automatically propose alternative solutions based on performance constraints.

2.4.7 PIDO Case Studies: Incorporate PIDO into MDA Process

To test this hypothesis, we will work with design teams to explore the design spaces on two case studies, and document the resulting design performance.
SECTION 2

Though the Green Dorm Project will be used as a case study for documenting a current MDA process, we shall start to apply new strategies to the project concurrently. A parametric BIM model of the Stanford Green Dorm will be constructed in Digital Project and evaluated as to how the added functionality of the models and the appropriate building analyses could be integrated into the process and design iterations of Taylor Engineering through the developed PIDO platform to support the project’s goals. The value and effectiveness of the PIDO process as compared to the current state practice will be measured and documented.

Our PIDO process will then be implemented on one of the Stanford University projects in which Arup is involved in the feasibility/conceptual design phase in 2008/2009.

2.4.8 Measure the Effectiveness Proposed Interventions to Current Practice

Using the process analysis framework developed in 2.4.1, we will measure the effectiveness of our proposed MDA process and PIDO framework on our selected case studies. We will utilize metrics based on time, quality, and clarity to compare the current and proposed MDA processes.

2.4.1 Document and Analyze Results

We will document the requirements for designers using PIDO, requirements for BIM, requirements for integration of analysis, requirements for feedback and iteration. We will analyze our measurements to identify the strengths and limitations of methodology, and recommend future steps.

2.5 RESEARCH UPDATE

Precourt has to date funded one year of research in this proposal. The next section gives an update on our progress on the above research.

2.5.1 BIM and Interoperability Research Update

Since April 2008, Benjamin Welle has been working as the Energy Thread Manager, Interoperability Program Team (IPTeam) for the Open Geospatial Consortium (OGC) AECOO Testbed. The Testbed is a joint initiative of the OGC and buildingSMART alliance and sponsored by leading AEC software user organizations. The Testbed features a global, hands-on, and collaborative rapid prototyping program designed to develop and deliver proven candidate standards. The current phase of the Testbed is focusing on developing information interoperability using Industry Foundation Classes (IFC) in two primary areas: quantity take-off and energy analysis.

Benjamin is the lead on the development of an Information Delivery Manual (IDM) for conceptual design energy simulation. An IDM is set out to define the key points or transactions, at which exchanges of information occur, identify the data in these transactions, specify how an application should share data in the transaction, and then allow applications to apply their user guidance as a response. During this process, Benjamin has been working with LBNL, Granlund, NIST, GSA, leading AEC firms, and leading CAD vendors to develop information exchange requirements for BIM and energy simulation, as well as evaluating the ability of the IFC data schema to support data exchanges for this business process. This work directly supports the research tasks 2.4.2, 2.4.3, and 2.4.4.
2.5.2 PIDO Research Update

Completed Research

Over the past 6 months, our research team has made significant progress in the PIDO platform development. We evaluated several commercial PIDO software called Phoenix Integration was evaluated and selected as our chosen PIDO environment. An interdisciplinary research team consisting of a Phoenix application engineer, several hired programmers, and two of my PhD students, Benjamin Welle (mechanical) and Forest Flager (structural) successfully integrated the energy simulation engine EnergyPlus, the structural performance software GSA, and the parametric BIM/CAD tool Digital Project by Gehry Technologies. A classroom case study was chosen to test the newly developed functionally. Figure 3 shows the classroom model used. The design variables considered in the classroom case study were building orientation, building length, window to wall ratio, and steel structural section types for beams, girders, and columns. The constraints applied to the analysis were a fixed floor area, structural and energy code requirements, and daylighting performance constraints. The objectives of the optimizations were to minimize lifecycle energy costs and structural first costs.

Figure 3
Classroom Case Study

Figures 4 and 5 below show some preliminary results from one of the design of experiments (DoE). Understanding complex performance trends in a visual manner that is easy to understand by design team members is one critical component of our research. For example, the contour plot in Figure 4 shows that for the particular design variables and performance constraints of the classroom building, the design with the smallest window to wall ratio and shortest length resulted in the most efficient design.
Figure 4
Visualization of Energy Performance Design Space for Classroom Building: Contour Plot

Figure 5
Visualization of Energy Performance Design Space for Classroom Building: Glyph Chart

Figure 6 shows the effectiveness of using an optimization algorithm in exploring the design space. Figure 6(a) is the result of a DoE, which took approximately 1882 simulations. Figure 6(b) shows the results of applying an optimization algorithm. As the graph shows, the optimization algorithm was able to identify the design region of best performance, and ultimately the best design option, in only 93 simulations, reducing simulation and analysis time by 95%.
Figure 7 shows the results of a multidisciplinary optimization between energy performance, structural performance, and cost using a genetic algorithm (GA). Each dot represents a design run, and the blue designs represent those that performed the best. The size of the design space was 55,000,000 possible design configurations. The GA took approximately 5000 simulations and 34 hours of run time to identify the family of Pareto Optimal solutions given the optimization performance constraints. The Pareto Front is shown at the bottom left-hand corner of the diagram as black x’s. While these results are preliminary, this information is extremely valuable for design teams when there are multiple objective preferences.
PIDO research has already been presented on an international webcast to an audience of 60 researchers and professionals, and more recently at the SimBuild 2008 conference in Berkeley on Friday, August 1st during a 90 minute Technical Session, as well as throughout the 3 day conference as a research poster. The conference drew over 250 industry leaders in building performance simulation. Throughout the conference and particularly after our Technical Session presentation, we had overwhelming interest and support for our research. Attached to this proposal are the presentation slides for the conference. We are currently writing a Journal paper to report on this work for the international journal of Information Technology in Construction (ITCon).

**Next Steps**

The next steps in the PIDO research are to develop more robust and flexible wrappers for EnergyPlus and Digital Project to handle more complex building types, integrate Radiance for daylighting simulations, and integrate Fluent for CFD simulation. After the technology is functioning effectively, we will apply it to several industry case studies and measure its effectiveness.
Advanced Test Cases
With successfully demonstration of the PIDO process for a small classroom building, the next step is to enable functionality to allow for multiple footprints, multiple zones per floor, and topology changes for multiple floors.

EnergyPlus Integration for Energy Simulation
While our current implementation successful integrated Energy Plus into the platform, there were limitations. More advanced script wrappers are necessary to handle more complex parametric models. Benjamin is currently working with a programmer to develop this next generation script wrapper. The ability to optimize construction type, HVAC system type, location, and lighting and equipment density will be added next.

Radiance Integration for Daylighting Simulation
Radiance is the most advanced lighting simulation tool on the market. Our goal is to integrate Radiance into the PIDO environment, and use it to calculate annual daylight performance metrics to be used as constraints in our PIDO optimizations. We have recently hired Zach Rogers, formerly with AEC Corporation and the developer of SPOT (Sensor Placement Optimization Tool) which is a front-end to Radiance. He has written several papers on dynamic daylighting performance metrics and has over 10 years of Radiance scripting experience. We are working with Zach to develop and test different methodologies available to calculate the annual dynamic performance metrics that will reduce simulation time to the necessary levels for our research.

Fluent Integration for CFD Simulation
Fluent is the one of the most advanced and widely used computation fluid dynamics (CFD) tools on the market. Our goal is to integrate Fluent into the PIDO environment, and use it to calculate thermal comfort performance metrics such as mean radiant temperature, air speed, and space temperature stratification to be used as constraints in our PIDO optimizations. We have discussed CFD solver and simulation strategies with Gianlucca Iaccarino, Professor of Mechanical Engineering in the Flow Physics and Computation Division of the Mechanical Engineering Department. He has offered his assistance in the Fluent script development for our PIDO research, as well as possible computing resources in his lab for distributed computing implementation. We have recently advertised widely throughout the university for some additional programming resources, and are currently in the process of interviewing candidates for an RA position.

Test Platform on Industry Projects
As mentioned in Section 2.4.7, the first case study we would like to implement the PIDO framework on is the Green Dorm (pending project initiation). We will also implement the PIDO framework on a mixed-use office/classroom building being designed for Stanford next year. Other project candidates include one of the many GSA projects reaching conceptual design phase early 2009. The effectiveness of the process will be evaluated and documented.

2.6 RESEARCH IMPACT

2.6.1 Contribution to Knowledge
When successful, this research will be the first of its kind to integrate a parametric BIM/CAD tool, an energy simulation engine, a daylighting simulation engine, and a CFD simulation engine into one operating environment for MDO trade studies. The proposed research will document the critical
design parameters and parametric relationships that must be considered in the effective design of energy, thermal comfort, and daylighting systems during the conceptual design phase. The research will specify how to implement the process and analysis methodologies in support of sustainable design goals through automated and integrated multidisciplinary optimization (MDO) using PIDO. We will provide a framework and measurements to scientifically assess the proposed methodologies compared to current AEC practice using time and number of design and analysis iterations as the units of analysis. This research will lead to an improved understanding of both the current AEC design process and a methodology that engages the important stakeholders, technologies, and information in that process.

### 2.6.2 Contribution to Professional Practice

The goal of this research is to reduce the amount of time required to generate and evaluate a design option in the area of energy, thermal comfort, and daylighting using model-based methods. A methodology will be developed that architects and engineers may use to reduce the simulation cycle time, and to formally investigate many more design alternatives within a given project timeline. This work will improve building performance in terms of initial cost, sustainability, and overall quality.

### 2.7 References


Haymaker, J., et. al. (2004). “Engineering test cases to motivate the formalization of an AEC project model as a directed acyclic graph of views and dependencies,” ITcon Vol. 9.

Information Delivery Manuals, buildingSMART:
[http://idm.buildingsmart.no/confluence/display/IDM/Home;jsessionid=5B9557C969B9AA2B7E55BB7FEC177C0](http://idm.buildingsmart.no/confluence/display/IDM/Home;jsessionid=5B9557C969B9AA2B7E55BB7FEC177C0)

Open Geospatial Consortium (OGC) AECOO Testbed:
2.8 SCHEDULE, RESULTS, AND BUDGET

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<tr>
<th>Task Name</th>
<th>Qtr 1, 2003</th>
<th>Qtr 2, 2003</th>
<th>Qtr 3, 2003</th>
<th>Qtr 4, 2003</th>
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<tbody>
<tr>
<td>1. Develop PIDO Interface for EnergyPlus, Radiance, and Fluent</td>
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<td>2. Implement a design space exploration for advanced test case using PIDO</td>
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<td>3. Fully develop process analysis framework</td>
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<td>4. Evaluate current design MDA processes for Green Dorm</td>
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<td>5. Explore data schema interoperability</td>
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<td>6. Research critical design parameters/parametric relationships for thermal performance</td>
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<td>7. Evaluate the potential of BIM to capture and utilize the design parameters</td>
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<td>8. Complete all building information modeling for the Green Dorm</td>
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<td>9. Implement the process in a PIDO software</td>
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<td>10. Use final framework to collect evaluation of methodologies from Green Dorm Case Study</td>
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<td>11. Evaluate current design MDA processes for a 2nd and 3rd case study from Conceptual Phase</td>
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<td>12. Complete all building information modeling for 2nd case study</td>
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<td>15. Conduct a comprehensive analysis of results for the entire research project</td>
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2.8.1 Schedule and Results

The results of this research will include:

- Process diagrams: We will develop detailed Narratives/IDMs to document the people, tools, reasoning, information used, and information constructed at each step in the current and improved processes.

- Measurement of current MDA practice: We will synthesize a framework for measuring processes, with data representing our findings of challenges within current MDA practice.

- A comprehensive evaluation of the current state of BIM design and analysis tools as applied to our research and a roadmap of recommended software modifications to resolve the identified weaknesses.

- A comprehensive survey of effective approaches for interoperability compatible with considered processes. The survey will document advantages and disadvantages of the approaches reviewed.

- A non-automated but integrated process enabling project team design generation and analysis tasks with the intervention of BIM technology and our chosen data schema approach. This process will be useful to design professionals who wish to integrate, but not necessarily optimize their design processes.

- An integrated and automated process using PIDO enabling the project team to optimize their design generation and analysis tasks for thermal performance and sustainable design. A functioning PIDO software platform fully integrated with EnergyPlus, Radiance, and Fluent will be available for use on actual design projects.

- A comprehensive report detailing the critical design parameters and parametric relationships for energy, thermal comfort, and daylighting conceptual design, the methodology for determining those factors, and how that information should be integrated with the BIM and PIDO applications.
- A comprehensive report documenting the results of all 8 quarters of research, including a comparison of methodology impacts between the two case studies, and an in depth analysis of the opportunities and challenges for improving building energy efficiency through advanced model-based design optimization methods.

### 2.8.2 Budget

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<tr>
<td>Computers and Software</td>
<td>10,000</td>
</tr>
<tr>
<td>RA Tuition</td>
<td>21,739</td>
</tr>
<tr>
<td>Total Direct Costs</td>
<td>140,000</td>
</tr>
<tr>
<td>Modified Total Direct Costs</td>
<td>140,000</td>
</tr>
</tbody>
</table>

**Rates Used in Budget Calculations**

- **Benefit Rates**
  - Faculty: UFY09 29.65%; UFY10 29.65%
  - Graduate: UFY09 04.00%; UFY10 04.00%
  - Staff: UFY09 29.65%; UFY10 29.65%

- **Indirect Cost Rate**
  - Special Rate: UFY09 00.00%; UFY10 00.00%

The budgeted salary amount is comprised of the direct effort for the project plus 8.85% vacation accrual/disability sick leave (DSL) for exempt employees and 7.50% for non-exempt employees. These amounts do not exceed total salary. The vacation accrual/DSL rates will be charged at the time of the salary expenditure. No net salary will be charged when the employee is on vacation, disability or worker’s compensation.