Formalizing and managing the dependencies between models

J. Haymaker
Center for Integrated Facility Engineering, Department of Civil and Environmental Engineering, Stanford University, Stanford, CA, USA

ABSTRACT: AEC professionals need information models that are structured for their specific tasks. They also need to be able to control the integration of these models with the models of other professionals. In this paper I propose methods for formalizing and managing the dependencies between information models. Using these methods, an AEC professional constructs an information model, called a Perspective, and specifies the sources and nature of its dependency on other Perspectives. He specifies the nature of the dependency using a reasoning algorithm called a Perspector that describes the automated or manual reasoning needed to construct the dependent Perspective from its source Perspectives. He uses Management Processes to control the integration of the dependent Perspective as its source Perspectives are iteratively modified. AEC professionals apply this method repeatedly and collaboratively to compose and control directed acyclic graphs of Perspectives and their dependencies, called Narratives. Narratives provide a simple, formal, visual, flexible, distributed, yet collaborative way to construct and control the integration of multiple task-specific Perspectives. They are intended to help AEC professionals communicate, integrate, and automate multidisciplinary design processes and the information models used in these processes.

Construction Informatics Digital Library http://itc.scix.net

1 INTRODUCTION

Architecture, Engineering, and Construction (AEC) projects must address many criteria, such as sustainability, function, structural stability, constructability, security, and cost. To do this work, AEC professionals produce a lot of information to describe everything from existing conditions, to project requirements, to design options, to design analyses, to construction documentation, to fabrication, to installation and as-built information. They usually construct this information from other information, which is often produced by other professionals, in other project phases, disciplines, and industries, and they need to maintain the integrity of their information as the project progresses.

That is, AEC professionals implicitly develop what I call narratives for their own work and interweave them with narratives of other engineers. The Oxford English Dictionary defines a narrative as "An account of a series of events, facts, etc., with the establishing of connections between them." In AEC practice, narratives help professionals expose cross-disciplinary impacts and integrate their work with the work of other project stakeholders; however, currently these narratives are not formally represented or managed. Surprisingly, the connections between information from different disciplines, in this case the dependencies, are not generically represented but rather stored in the heads of the professionals. This way of constructing, organizing, and communicating project information is proving to be time-consuming, error-prone, and expensive.

In this workshop we are exploring how to expand the IFC specification to "support links between objects in two different instantiated models." In this position paper, I propose that as part of this specification, we formalize the sources, status and nature of the dependencies between the models that contain these objects. I also propose we formalize Management Processes to help control the integration of these models. First, I introduce our current formalization for Narratives. Next, I'll show their application to two test cases from different parts of the building lifecycle. Finally I'll discuss some of the benefits and limitations of Narratives.

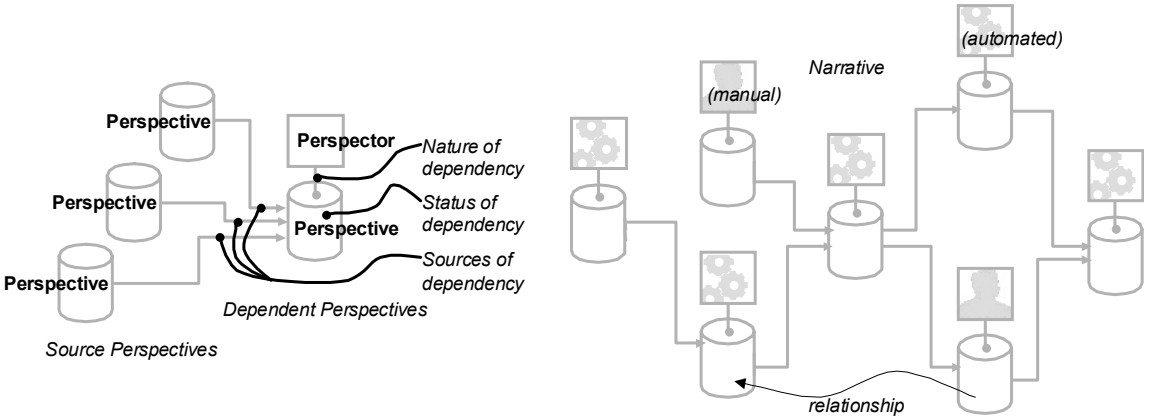


Figure 1: Formalizing the dependency between task-specific information. **A.** Formalizing the sources, nature, and status of the dependency of a dependent view on source views. **B.** A Narrative emerges from the repeated application of the formalism described in A.

2 NARRATIVES: PERSPECTIVES AND THEIR DEPENDENCIES.

In Haymaker et al 2004 a, we proposed that AEC professionals could have addressed the difficulties they are currently having constructing and integrating their task-specific information by formalizing Narratives. Specifically, we propose that design and construction processes could be augmented by, if not founded on, simple formal, generic, expressive methods to construct information by formalizing its dependency on other disciplines' information and by controlling the integration of this information as the project progresses. A formal Narrative could emerge as AEC professionals iteratively apply such methods.

We proposed formalization for Narratives. Using what we call the Perspective Approach AEC professionals specify the sources, status and nature of the dependency of their information model, called a Perspective, on other Perspectives.

Sources: The source Perspectives on which a dependent Perspective depends.

Status: Integration status of a Perspective with respect to its source Perspectives.

Nature: The reasoning method (automated or manual) that constructs the information in the dependent Perspective from information in the source Perspectives. We call this reasoning method a Perspector.

Fig. 1A diagrams this formalization of the dependency of dependent information on source Perspectives(s). Fig. 1B shows that a formal Narrative can emerge form the iterative application of this representation method. It also shows that the Perspectors are generic, and can therefore specify either human or automated, off-the-shelf or user defined reasoning.

Because a Perspector analyzes information in source Perspectives to produce information in dependent Perspectives, any Perspector can itself be decomposed into a sub-Narrative. Such decomposition aids in the thought process when constructing a Narrative, as well as the readability of a composed Narrative. I provide examples of this decomposition in Figures 2 & 3.

The Perspective Approach also formalizes Management Processes to help AEC professionals control the integration of these Narratives. The first Management Process assures that the dependencies between Perspectives are properly constructed:

Management Process 1: When constructing a new dependent Perspective, construct a reference to the source Perspective in the dependent Perspective's Source Perspectives list, and place a reference to the dependent Perspective in each source Perspective's Dependent Perspectives list.

The second Management Process assures that the integration status of all Perspectives is up to date with respect to the iteratively modified source Perspectives on which they depend:

Management Process 2: Before (re)constructing a Perspective, check that each source Perspective's Integration Status is set to Integrated. While (re)constructing a Perspective, set that Perspective's Integration Status to Being_Integrated. After (re)constructing a Perspective, set that Perspective's Integration Status to Integrated, and recursively set all dependent Perspectives' Integration Status to Not_Integrated.

Construction Informatics Digital Library http://itc.scix.net

3 EXAMPLES OF NARRATIVES

In this section, I describe two Narratives that I composed to address problems I observed on real AEC projects. The first Narrative (see Figure 2) formalizes a multidisciplinary cost benefit analysis for different design strategies, such as an atrium and a green roof. The second Narrative (see Figure 3) formalizes an automated design process to detail the metal deck attachments that connect the project's concrete slabs (designed by the architect) , and the projects steel beams (designed by the steel detailer).

I also briefly describe an implementation of the second Narrative in the computer.

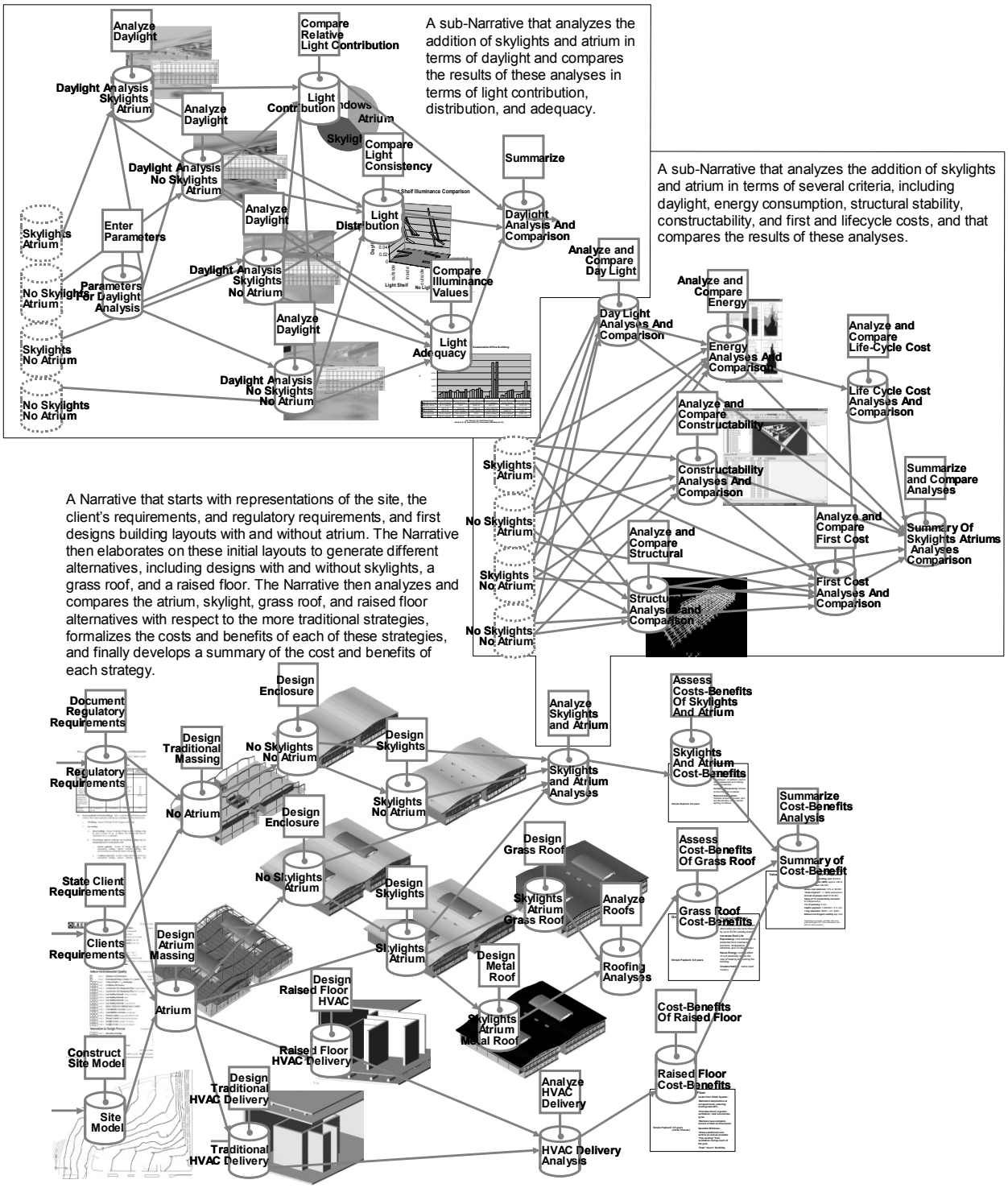
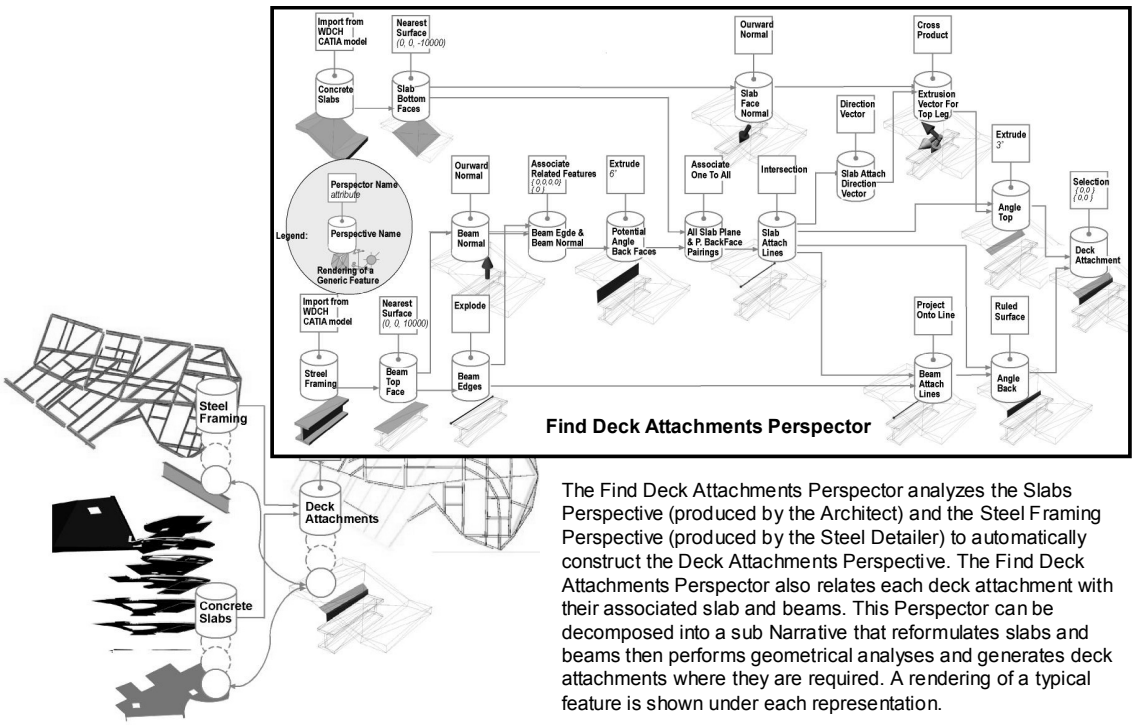


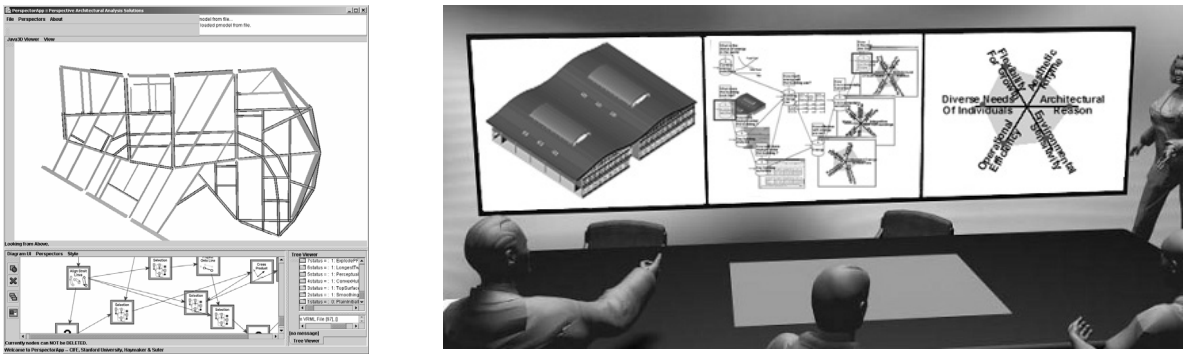
Figure 2: A conceptual Narrative to formalize a cost-benefit analysis during schematic design. The figure shows that the "Analyze Skylights and Atrium" Perspector decomposes into a Narrative that performs this analysis. The figure also shows that within this sub-Narrative, the "Analyze and Compare Daylight" Perspector decomposes into a sub-Narrative that performs this analysis.

Construction Informatics Digital Library http://itc.scix.net



The Find Deck Attachments Perspector analyzes the Slabs Perspective (produced by the Architect) and the Steel Framing Perspective (produced by the Steel Detailer) to automatically construct the Deck Attachments Perspective. The Find Deck Attachments Perspector also relates each deck attachment with their associated slab and beams. This Perspector can be decomposed into a sub Narrative that reformulates slabs and beams then performs geometrical analyses and generates deck attachments where they are required. A rendering of a typical feature is shown under each representation.

Figure 3: A Narrative to automatically design deck attachments. The figure shows that the "Find Deck Attachments" Perspector decomposes into a sub-Narrative that automatically identifies where these conditions are required, and then designs each required deck attachment.



A **B**

Figure 4: Implementations of a *Narrator* that enables engineers to quickly connect reasoning and representations into MDA Narratives. **A.** Our initial software, which constructs and controls geometric Narratives, with the implemented deck attachment Narrative. **B.** A future implementation of the Narrator mocked-up for the I-Room. In this scenario, the team is iteratively modifying a design of the building (the left screen) as they work to achieve their project goals (right screen). The Narrative is on the center screen.

We implemented a computer program, called PerspectorApp (See Figure 4A), that allows an AEC professional to compose Narratives of geometric Perspectives and Perspectors like the one described in Figure 3, and control their integration. Future work will explore computer programs that allow AEC professionals to construct and control Narratives with Perspectives containing arbitrary datatypes, allow AEC teams to construct and control NArratives in collaborative environments like the Information Workspace (Johanson et al 2002), and allow distributed project teams to constrcut and control Narratives over the web.

Using PerspectorApp, we found that Perspectors could be reused in different Narratives. Figure 5 shows that several of the Perspectors used in the deck attachment Narrative were also used in the Find Cantilever Conditions Narrative, that analyzed the ceiling system and it's structural supports for cantilever conditions. Given a set of representational primitives (such as those proposed in the IFC) a finite set of Perspectors might be defined that can be composed into Narratives and subsumed to define arbitrarily complex Perspectors, minimizing or eliminating the need to program.

Construction Informatics Digital Library http://itc.scix.net

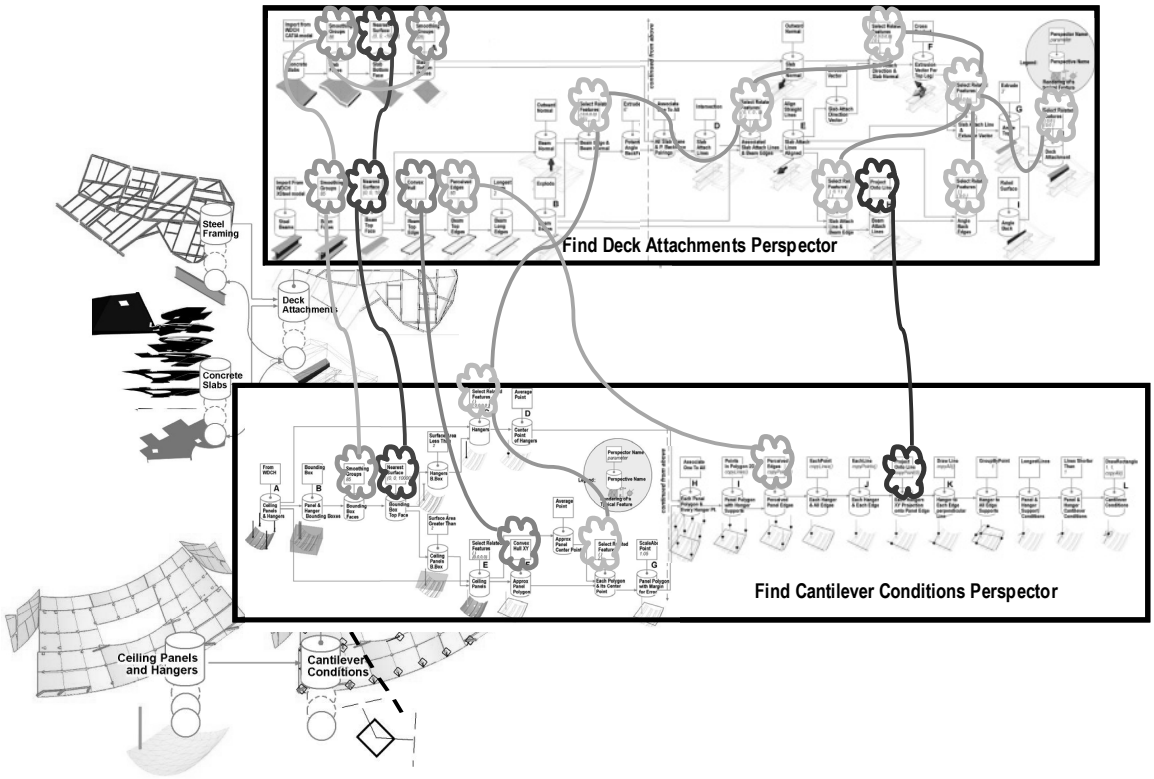


Figure 5: Many of the same low-level Perspectors employed to design deck attachments were reused to analyze for cantilever conditions. I hypothesize that a finite language of low-level generic representation and reasoning can be developed that AEC professionals can compose to construct discipline-specific Narratives.

4 LIMITATIONS AND BENEFITS OF NARRATIVES

In this section I conclude with a discussion of the benefits and limitations that I have observed so far with Narratives.

4.1 *Limitations of Narratives*

- Limited Representation: In PerspectorApp, geometric Perspectives contain Features that contain Surfaces, Lines, and Points. Other geometric data types, such as NURBS, Solid Models, other non-geometric data types, and more complex view structures than a collection of Features can increase the expressive power of Perspectives, however potentially at the expense of greater complexity for AEC professionals who need to understand the Perspectives and the Perspectors that transform them. Formalizing Perspectives that contain IFC data types, and Perspectors that are programmed to expect these data types are future work.
- Limited Reasoning: While they perform well on the test cases, the individual geometric Perspectors and Narratives we've implemented were chosen in a somewhat ad-hoc manner to address our test cases. They are an initial investigation into the power and generality of the Perspective Approach. New test cases will require some new Perspectors.
- Limited Management: Due to the acyclic nature of the formalism, the Perspective Approach does not support cycles in dependencies. While acknowledging that the dependencies between information models can often be cyclical (for example the architect may revise the location of slabs or beams based on the number and size of deck attachments) the conceptual simplicity of formalizing a project model as a directed acyclic graph of views and their dependencies provides an appropriate level of computational support for multidisciplinary, constructive, iterative, and unique AEC projects. AEC professionals can manually manage the cycles in the dependencies by modifying source Perspectives in response to the information in dependent Perspectives.
- Limited Implementation: We did not address issues of version management, access control, computational performance, UI tools to enable manual Perspectors, or distribution of Perspectors and Perspectives across a network.
- Limited Validation: We have shown the Perspective Approach to be adequately generic, expressive, formal, and simple to address certain test cases described in this paper. However, more explicit formalization of these criteria, testing for these criteria on more test cases, and more explicit comparisons of the Perspective Approach against other approaches with respect to these criteria are required.

Construction Informatics Digital Library http://itc.scix.net

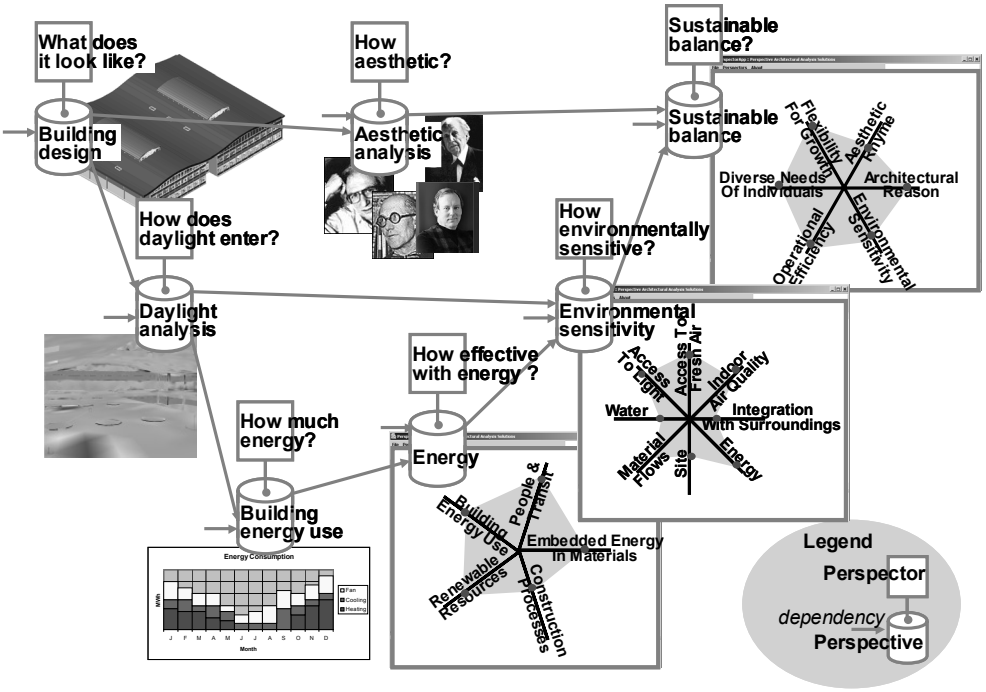


Figure 6: A partial conceptual Narrative to explicitly measure a project in terms of its goals. Starting with representations describing the current energy context, the building geometry, day lighting analysis, and other representations (not shown), the Narrative constructs a representation of Projected energy performance of the building. From the Building Energy Use representation and from other representations (not shown) the Narrative constructs a representation describing the Energy performance for the entire project. From the Energy representation and from other representations (not shown), the Narrative constructs a representation of the Environmental Sensitivity of the project. From the Environmental Sensitivity Representation, and from other representations (not shown), the Narrative constructs a representation describing the overall Performance in terms of the project's core goals. The project team can iteratively modify the Building Design Perspective while they search for a design that optimally satisfies all their goals.

4.2 *Advantages of Narratives*

While there are limitations in our current implementation of Narratives, I see many benefits to the formalization of Narratives. Among the benefits, Narratives are:

- *General*: The representation generically describes the sources, status, and nature of dependencies between Perspectives and provides generic Management Processes to enable engineers to easily control the integration of these Perspectives. In addition, I have shown that once a representational schema for the data in Perspectives is chosen, individual Perspectors can be reused for different test cases.
- *Simple*: To construct a new Perspective, all an AEC professional needs to do is specify its source Perspectives (currently done in PerspectorApp by drawing arrows), and specify it's Perspector (from a drop down list).
- *Flexible*: New Perspectives can be added to a Narrative at any time, making it possible for the project model to emerge over time as the issues of the project are discovered and refined.
- *Distributed*: While the initial implementation is on a single computer, the formalism lends itself to a distributed implementation, where AEC professionals can connect their task specific Perspectives over the internet.
- *Formal*: As shown with the implementations, Narratives can be implemented in the computer.

A general, flexible, simple, formal, and distributed formalism like Narratives can provide the basis for a language that can help AEC professionals better communicate, integrate, and automate and thus improve their multidisciplinary design processes:

- *Communication*: Narratives contain the graphical view of the dependencies between information models, providing a common way to communicate the task inter-dependencies and their status. These diagrams make it possible to collaboratively design and execute the design process.
- *Integration*: Each Perspective contains a formalization of it's status, and the Management Processes help control the status, enabling AEC professionals to explicitly control the integration of their Perspectives.
- *Automation*: As shown in the test cases, Perspectors and entire Narratives can be automated to provide fast and accurate dependent Perspectives. As more and more design tasks can be formalized and automated they can replace manual Perspectors. Therefore Narratives provide an incremental framework in which to continuously incorporate best of breed software.
- *Better Design Processes*: Enabling AEC professionals to explicitly define their Perspectives and their dependencies, and to control and automate these processes, is expected to lead to better de-

Construction Informatics Digital Library http://itc.scix.net

signs. Figure 6 shows a conceptual Narrative to explicitly track a project with an architect's stated goals for the project: To design a project that "combines aesthetic rhyme with architectural reason, environmental sensitivity with operational efficiency, the diverse needs of individual employees with the scale and flexibility required by a growing company (Bay Area Council, 2000)."

5 REFERENCES

Bay Area Council, (2000), "Environmental Building Design, (901 Cherry Offices) at Gap Inc.", *Best Practices*, Bay Area Council, http://bacqube.bayareacouncil.org/bp/bestpractices/bp185.html

Haymaker J, Fischer M, Kunz J and Suter B (2004a). "Engineering test cases to motivate the formalization of an AEC project model as a directed acyclic graph of views and dependencies," ITcon Vol. 9, pg. 419-41, http://www.itcon.org/2004/30

Haymaker J., Suter, B., Fischer, M., and Kunz, J. (2004b). "The Perspective Approach: Enabling Engineers to Construct and Integrate Geometric Views and Generate an Evolving Project Model," Working Paper Nr 081, Center For Integrated Facility Engineering, Stanford University.

Haymaker J., Kunz, J., Suter, B., and Fischer, M. (2004c). "Perspectors: composable, reusable reasoning modules to construct an engineering view from other engineering views," Advanced Engineering Informatics, Vol 18/1 pp 49-67

IAI (2004). "International Alliance for Interoperability (Home Page) [online]". URL: http://www.iai-na.org/. Accessed April 27, 2005.

Johanson, B., Fox, A., and Winograd, T. (2002). "The Interactive Workspaces Project: Experiences with Ubiquitous Computing Rooms," IEEE Pervasive Computing Magazine 1(2), April-June 2002

Construction Informatics Digital Library http://itc.scix.net