Building Science by Design: Developing a Building Information System and Teaching Architecture with Analytical Case Studies

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Abstract: Building designers are expected to employ all the technical means that modern-day engineering provides. This calls not only for a more technical-scientific orientation in the training of architects, but also for readily effective building design tools. A survey of the available resources for supporting the building design process, however, shows that computer-based design guidance is still largely based on the working concerns of engineers and reflects little of the case-based reasoning style of architects. Moreover, many fundamental aspects for making design decisions are virtually eliminated from the information structure of the given systems, in particular, the spatial context of technical design parameters in physical, geometric terms. The paper presents a long-term IT development project aimed at building an accessible bridge between the information needs of architects and the information provided by the building sciences, in the educational context of a technical university program of architecture.

1. Introduction

The professions of architecture and civil engineering are often considered together as a generalized building design and construction discipline ("AEC") that ideally works as one to optimally design our built environment. There are, however, obvious and fundamental differences in the respective working methods of each profession, which are reflected in mutually distinct styles of academic training. Especially the differing approaches to rendering and communicating design concerns impede interdisciplinary cooperation in both training and practice.

Although technical universities provide both architecture and engineering programs, these generally remain separate faculties with distinct teaching and learning styles that reflect the dichotomy between the practicing professions. Building science is a primarily academic discipline that is closely related to (but not identical with) the professional disciplines of architecture and civil engineering. As such, it can be seen as a potential bridge between the two professions in education.

The fundamental principles of empirical scientific methods are used to enrich both architectural and technical thinking. The development work focuses on the interdisciplinary subject matter of advanced structural design and construction methods, whereby two, originally separate lines of research activity are intertwined with the teaching activities at the authors' university. One was a publicly funded initiative at the faculty level for employing all manner of "new media" in the architecture curriculum. The other revolves around a research project at the department level that is currently in progress and aimed at developing building information systems as interactive design support. We recently combined both sets of activities in an integrated project titled "*archistructura*: Media Development System for Building Science and Structural Design," which encompasses three primary application areas that are being developed in parallel:

- structural design support for architects and engineers,
- courseware and accompanying learning resources, as well as
- a building collection with integrated case studies and model-enhanced documentation.

The following paper focuses on the application "building collection" within the overall *archistructura* framework.

2. Objectives and Methodology

Promoting the sustainability of quality information is an accompanying objective behind the IT-based development of the *architstructura* system in the given educational context. Knowing that one's own work will not only be registered for academic credit, but also maintained and communicated to others in a larger framework is a motivating factor for students and instructors alike. In particular, the prospect of having their work published (online) as a definitive case study in the building collection has proven to effectively improve the quality of student work.
The diagram below (Fig. 1) schematically delineates how the content development framework relates to the application and publishing framework via shared collections of application objects. This concept is loosely based on the general SCORM® specification ("Sharable Content Object Reference Model," Advanced Distributed Learning 2003, Nissi 2003). All "raw content" items (data files) are tied into the system through flexibly implemented metadata structures, which are refined and differentiated as needed (see also "3.1 Structural Data Quality"). The basic system has also been conceived with an explicit aim towards cross-lingual functionality, such that all semantic metadata vocabulary is collected and managed in internationalization tables for consistent translation.

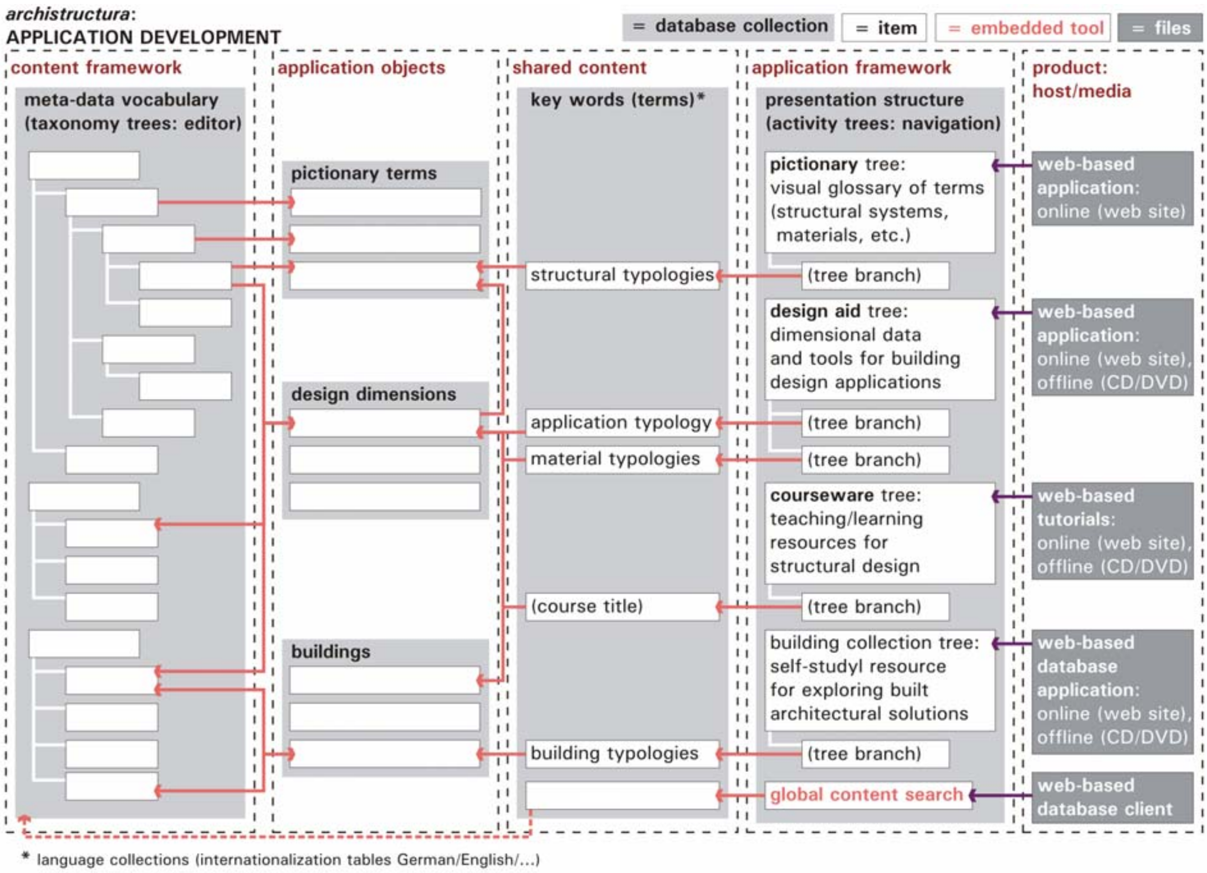

Figure 1: Application development scheme behind the overall *architstructura* concept [1].

2.1 Architectural Design Guidance

Compared to the relatively linear workflow of engineering, the architectural design process follows "loopier" and much less predictable sequences of iterations through design issues (cf., Schank 1984, Kühn & Herzog 1993). Consequently, most learning processes in the study of architecture are complexly project-based rather than sequentially lesson-based (cf., Nissi 2003), and need to be addressed quite differently than in more traditional types of engineering courseware (cf., Jahnke 2000).

[1] The *architstructura* website in German: http://www.iti.tuwien.ac.at/projekte/ars/index_de.htm (English: /index_en.htm)

At various stages in the process of developing a design idea, the architecture student needs to investigate examples of related building design solutions, that is, to learn from the experience of others and relate this knowledge to his or her own task at hand. Such case-based reasoning is central to developing design skills (cf., Gero et al. 1991, Heylighen & Verstijnen 2003). To this end, a fully structured collection of case studies forms a central part of the *archistructura* system, making it into a technical "design atlas" for architects.

At other points in the design process, the architect is confronted with decisions regarding clearly definable design parameters in the given context, and needs to establish and compare options for specific design values. Though technical aspects of a building, in particular those that demand a high degree of pre-specification for assessment, are only of peripheral interest to the architect at early design stages, tools that help students gain a feel for the sensitivity of design parameters can be very useful. The framework for design tool development is being successively deduced from building design case studies in order to clarify the types of design questions and information needs that arise with each design stage.

With respect to the overall system, the conceptual formulation of the application method accounts for future development and expansion of the realized system. The modular and flexible implementation scheme ensures that the application profile can be adapted to incorporate future developments in building data processing. The first set of implemented tools includes features for visualizing the interdependence of span length and beam depth in design dimensions. The tools needed for calculating preliminary design dimensions will be accessible directly within the design-support environment. Future stages of development are projected to allow the user to select, for example, a set of joint detail solutions from the building database and subsequently evaluate their load-bearing capacity and stiffness with customized dimensions.

As a substantial enhancement to the building collection, a web-based tool for visualizing the simulated structural behavior of three-dimensional building models is currently under development. The main didactic issues up to this stage have involved establishing a consistent and complete 3D convention for structural system diagrams that is as related to familiar 2D conventions and as intuitively "legible" for architecture students as possible. To this end, the visualization techniques used in a number of structural simulation programs for engineers were compared and evaluated according to didactic criteria in the context of the structural design curriculum for architects. An example of alternate views for a three-dimensional detail of such a structural system model is depicted below (Fig. 2).

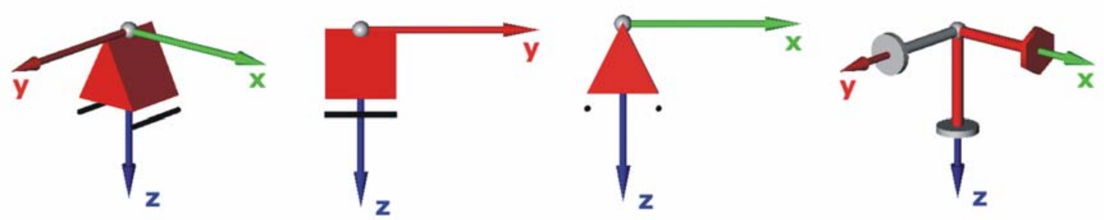

Figure 2: A complex support situation visualized as a node of a structural behavior model: standard (isometric and orthogonal) and detail (isometric) views – excerpted from an engineering grant thesis (R. Hauck) on 3D visualization as part of the research project "Building Information Systems as Interactive Design Support."

2.2 Teaching with Analytical Case Studies

Engineering quantities can only serve to inform the building design process effectively if communicated on the basis of comparisons that allow the architect to relate them qualitatively. This entails visually supporting the interpretive translation of numeric differentials ("more/less") into the kinds of semantic differentials that a designer uses to compare competing options, such as "better/worse," "efficient/inefficient," "light/heavy," and so on. Since architects are well-trained to "read" spatial patterns (Alexander et al. 1977), the most effective means of communicating technical information is to employ visualization methods that relate quantitative design values in their spatial context.

Buildings are highly complex physical entities that can be analyzed – and even simulated – according to many different types of criteria. At the heart of the "building science by design" approach lies the systematic analysis of existing building structures to reveal the relationships between space, force, energy, and construction methods. It is in the intellectual process of abstraction by means of modeling that students effectively "reconstruct" the design process and thus gain a deeper understanding of the physical and technical considerations underlying the finished product. The modeling principles are analogous to those for defining theoretical simulation models for the computer-based calculation of structural and thermal behavior.

Since architects are accustomed to thinking in three dimensions and working with computer-aided drafting and design systems (CAD), it makes sense to use standard 3D modeling applications as the initial working environment for the process of abstraction. This allows students to concentrate on the theoretical concepts and principles communicated in the 3D models, rather than on learning to use specialized simulation software (Fig. 3).

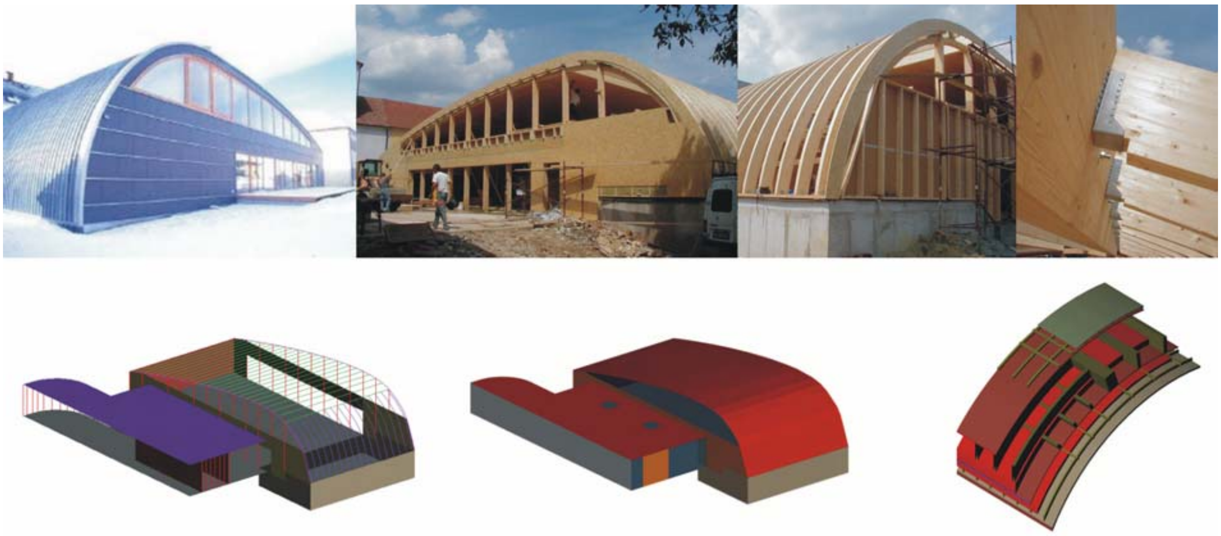

Figure 3: Photo documentation of a building (finished and under construction) and three types of analytical 3D models of the same building (load-bearing structure, thermal envelope, and construction detail) – excerpted from a student case study (M. Wagensonner) for a seminar on energy-efficient timber construction methods.

The process analysis that is needed to specify the design-support application of the *archistructura* system goes hand-in-hand with the kind of analytical case studies that are meaningful in architectural education. This stage of system development is currently being incorporated directly into suitably defined coursework by a three-tiered strategy:

- building case research and model-based analysis work in seminar-style courses,
- structured results documentation for assessment and publication at the end of each course,
- integration into the building collection of *archistructura*, as a resource for other students as well as for further model development in advanced courses (structural and thermal behavior simulation for architects and engineers).

A detailed description of the technical means and workflow used is provided in section “3.2 Workflow and Preliminary Results.”

3. Implemented Technologies and Applications

3.1 Structural Data Quality

Comprehensive concepts of integrated data management on the basis of so-called product data models have been in development since the early 1990’s. Product data models formally consist of data structures that contain not only the geometry of a digital building model, but also further information necessary for planning, execution and facility management (Hörenbaum et al. 1998). Admittedly, the application of product model data is not yet standard planning practice. Technical drawings are usually drawn in two dimensions; the corresponding CAD software does not store additional information concerning used materials, execution timetables, or expenses. This information is generally gathered and processed in separate programs, with the result that it can often only be exchanged between applications by re-entering the data manually.
Documents of executed buildings are mainly available in the form of common text files, digital images, spreadsheet and other calculation data, as well as CAD drawings. Unfortunately, the existing data is often incomplete or not accurate enough to be mapped directly to existing schemata for product modeling. This requires a considerable amount of additional work, which led us to adopt an interim strategy of only partially structuring the data before conversion into intermediate working formats.

The quality of existing documents can be differentiated as follows (Popova et al. 2002):

- *structured data* that are represented by standardized product models, relational tables, and/or object-oriented structures;
- *weakly structured data* that cannot be mapped directly to product models (e.g., word-processing and spreadsheet programs);
- *raw data* (e.g., raster images, graphics, audio or video files).

In order to provide uniform access to large amounts of already existing data, it was necessary to create a working data format that allows classification and indexing. This included conversion of structured and weakly structured data, as well as the creation of descriptive data sets (meta-data) for the existing raw data files. As an intermediate format for weakly structured data, the *extensible mark-up language* (XML [2]) proved especially well-suited. XML offers various advantages making it ideal for the above mentioned purposes:

- Many recent versions of software applications used in building design support the export of XML data, and can thus be used to convert older files.
- Various tools exist for processing XML data, thus enabling rapid application development.
- Conversion and automated processing of various XML formats into a common working format is facilitated by means of *extensible style-sheet language transformation* (XSLT).
- XML mappings of product model schemata already exist or are currently being developed. Upgrading the weakly structured representation of the intermediate format to a fully structured one of an appropriate product model should, therefore, soon be possible.

Accessing the classified and newly ordered data called for a database system that allows the centralized storage of the data in combination with applications for querying defined data sets by flexibly defined criteria (e.g., common database systems).

3.2 Workflow and Preliminary Results

The technical means for implementing the application concept have been developed and tested in the context of several architecture courses carried out at the authors' institution. For the analysis phase of such seminar-style courses, the teaching staff provides partial building documentation in the form of data files. Participating students then research the assigned building to complement the available documentation as needed for the analytical modeling work. The collected data consists mainly of digital photographs and scanned drawings; in some instances, text files of previous student work are available. Due to the enormous amount of data (typically several hundred megabytes), the material is issued to the participating students on CD-ROM.

The analysis phase is accompanied by text-based work in extensive spreadsheet forms ("worksheets"), which are used to document the content and elemental structure of the CAD models. The standard office application also allows preliminary (2D) model representations to easily be inserted in the formatted worksheets. To support an orderly documentation of the modeling work in progress, such graphics are indexed in a separate table of model renderings. After proof reading by the instructors, the sets of worksheets ("workbooks") are exported as XML data. It is possible to convert existing data and add describing meta-data to such pre-formatted information without additional, platform-specialized software.

Communication and distribution of working media via Internet is vitally important during course execution. The preformatted workbooks, instructions for scientific work, and other electronic resources are provided for download. The identification of typological elements in the building models is aided by the use of visual glossaries of terms (so-called "pictionaries") that are accessible directly online. The pictionary application is based on the same hierarchically structured and continually refined taxonomy trees used to structure the content of other applications in the *archistructura* system (see Fig. 1).

After transformation into XML data, the full results of completed coursework are integrated into a developmental database at the end of the semester. Using a so-called XML publishing framework (Cocoon [3]), HTML pages are automatically created from the database content and published via a web server.

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[2] More about XML: *http://www.w3.org/XML/*

[3] More about the *Apache Cocoon* web development framework: *http://cocoon.apache.org*

4. Summary and Prospects

Courses spanning three semesters have been carried out in the described manner to date. Approximately 60 comprehensive building case studies have been indexed and thoroughly re-structured for the new building information system *archistructura*. The publication of students' work has significantly increased their motivation and also improved the overall quality of their work. Moreover, they are integrally involved in the knowledge generation and management process. Several potential ways to further develop and enhance the application flow of such courses have been identified. Currently, the following improvements and extensions are on the agenda:

- Specific courses are being re-designed and better documented to support integration in the online learning resource system.
- The created resources are being used by other departments to encompass more facets of the architecture curriculum.
- The database system is being extended to support additional web applications (e.g., visualization of 3D simulation models, interactive semantic profiles to describe buildings, etc.).

Suitable sets of building models will subsequently be mapped to standardized product models. Additional potential can be realized by further developing the implemented system to serve as a fully parameterized product model database. Embedded in the full *archistructura* context, such resources can effectively span the "design concern gap" between architects and engineers.

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