Semantic Differential Analysis in Architectural Education: The Leverage of Polarity Profiles in Case-based Reasoning

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Abstract: Case-based reasoning and complex problem solving skills play a central role in the interdisciplinary educational domain of architecture and engineering. A faceted approach for enhancing case studies of building precedents serves to activate critical thinking about the built environment at an integral level by employing a specific system of semantic differentials. The data basis consists of comparable opinion polls at three different, editorially monitored levels, which are rendered in composite views for interpretation by instructors and students. The semantic challenges of and experiences gained in the course of implementing the application concept in a web-based environment are discussed.

1. Introduction

Case-based reasoning skills – the ability to analyze solutions to similar problems and to draw conclusions by analogy – are a central qualification that architecture students must acquire and practice in the course of their studies. The training of architects thus traditionally revolves around design process simulation in the form of "design studios," in which the assignment is to find a design solution for a building given a description of a realistic situation (site, function, etc.). Comprising over half of the curriculum in typical architecture programs, such studio teaching is inherently constructivist in approach and relies heavily on engaging students in the study of precedents related to the problem at hand.

Though civil engineering is closely related to architecture in practice by virtue of a common aim to design our built environment as competently as possible, there are fundamental differences in the respective working methods and immediate design concerns of each field. These differences are reflected in very distinct styles of academic training, even at universities which profess to offer interdisciplinary programs for both professional degrees.

With an aim to better bridge the "design concern gap" between architecture and engineering, a "building science by design" approach has been formulated that focuses on the interdisciplinary subject matter of advanced structural design and construction methods (Pfeiffer-Rudy & Jaksch 2004). The development work in this area intertwines various lines of research activity with the teaching activities at the author's university under the heading of an integrated project titled "*architectura*: Media Development System for Building Science and Structural Design." The overall *architectura* concept encompasses the following three main application areas, which are being developed in parallel:

- *design aids* – structural design support for architects and engineers,
- *study aids* – courseware and accompanying learning resources, as well as
- *buildings* – a database of documented design precedents with integrated case studies (Fig. 1).

Working versions of the various components are being provided to students in a web-publishing framework on a running basis, targeting content needs as they arise in conjunction with the current curriculum for both the architecture and engineering programs [1].

The following paper focuses on a recent enhancement to the *architistructura* application *buildings*: the introduction of so-called "polarity profiles." These have proven especially useful as a teaching tool in leveraging the quality of the building collection as a case-based information resource within the overall educational framework.

[1] General *architistructura* URL: *http://www.architistructura.net* (English and German); see also embedded version in department website (with access to extended student resources): *http://www.iti.tuwien.ac.at*.

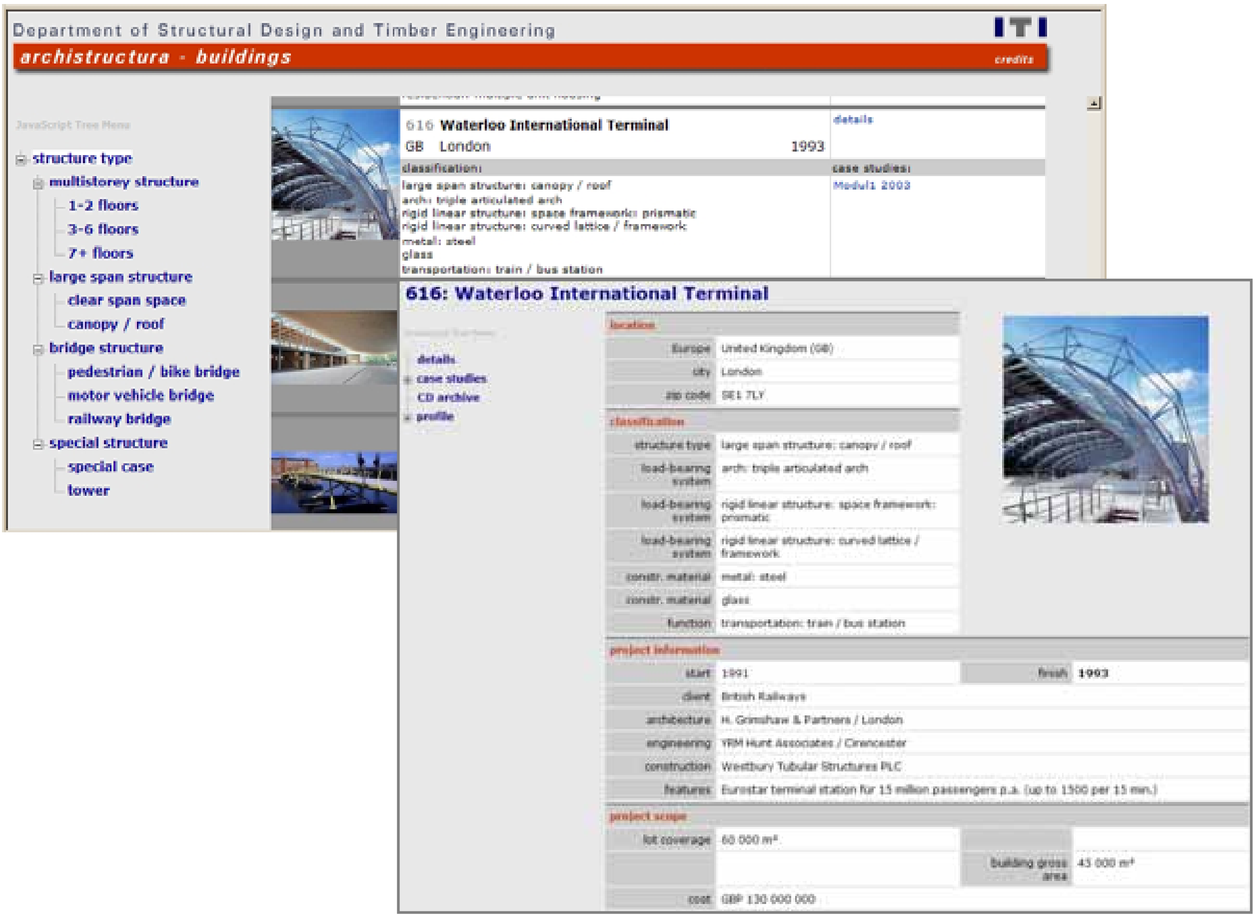

Figure 1: Screenshots of search results and building detail information in *archistructura*.

2. Objectives and Methodology

Several investigations have been done to confirm the importance of case-based reasoning (CBR) systems to improve the quality of student design work in an academic setting (cf., Heylighen & Verstijnen 2003). The results of such experiments are, however, generally anecdotal and provide little evidence of how – or even whether – architecture students intellectually process the knowledge provided to them in the employed CBR system.

Another issue that is rarely addressed is the problem of obtaining and maintaining informative documentation for a statistically relevant number of cases. Experience has shown time and again that content development with respect to both quality and quantity is the most decisive (and time consuming) factor in establishing effective knowledge management systems (cf., Schank 1984, Gero et al. 1991, Simoff & Maher 1998, Nissi 2003, Davies et al. 2003).

The *archistructura* initiative seeks to promote the sustainability of quality information by engaging students directly in the development of content that is worthy of publication in an online building collection (Pfeiffer-Rudy & Jaksch 2004). The editorial decision as to which buildings shall be analyzed in the context of current courses is largely based on what may be deemed useful to students in their future design work.

2.1 Semantic Differentials and Polarity Profiles

While analytical case studies are an important basis for refining technical design solutions, the conceptual decision to take a particular case as a precedent in the first place must be based on a judgment of the building as a whole, that is, as a complete solution to a complex design problem (Alexander 1979). Technical information 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. In other words, the case-based detail knowledge must be tied to the kinds of semantic differentials that enable an interpretive comparison of competing options, such as “better/worse,” “efficient/inefficient,” “light/heavy,” and so on (Pfeiffer-Rudy 2003).

So-called *polarity profiles* describe the experiential impact of buildings by such a method of semantic differentials. Based on a German-language poll covering 46 psychological-architectural polarities, the perceived qualities of a building are reviewed in the span between semantically opposing terms (Fig. 2). The original CEMAG method, for which the questionnaire was developed, prescribes extensively detailed building assessments through architecture experts for statistical correlation analysis with profile data (Joedicke et al. 1977). In contrast to the cited method, the "expert opinion" in *archistructura* is represented by students who have thoroughly treated the given building in the context of academic coursework, i.e. by “case study authors” (blue bars in Fig. 2). These reviews are handled separately from data collected in other applications (red bars in Fig. 2).

Due to the international distribution of the collection, profile data stems mainly from people who have never experienced the given building directly. This also applies to those case study authors who, because the object of their study was beyond physical reach, had to rely on secondary information alone (literature, photos, etc.) to assess their impressions. Obviously, such accounts of a conceived “experiential impact” without first-hand “experience” are only of conditional validity and may say more about the qualities of a particular case study than of the building itself (especially in cases where supporting information was insufficient or misinterpreted). Nevertheless, it has still proven worthwhile to have students review the buildings in this manner as the reviewing process itself encourages the critical reflection of architectural qualities in other terms, beyond the immediate “point” of a given assignment. It also provides an excellent introduction for students to get familiarized with other students’ work in *archistructura* and, at the same time, to give valuable feedback to the system’s content developers and editors (see also next section, “Application Stages and Results”).

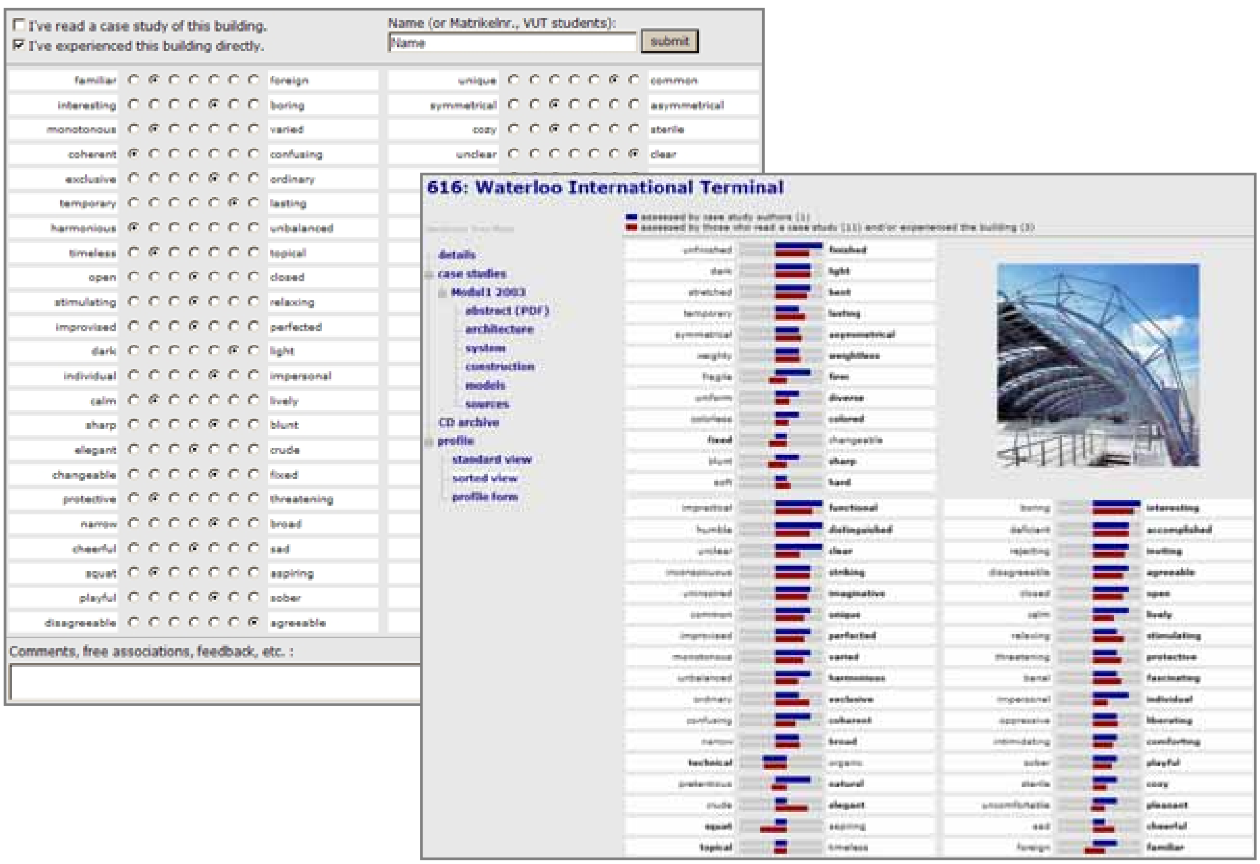

Figure 2: Screenshot of the online questionnaire behind the composite polarity profile (sorted view) for a given building in the collection.

2.2 Interpreting Polarity Profiles

Correlative comparisons of different buildings with similar polarity profiles and recurring morphological features can reveal relationships between architectural characteristics and associative impressions that reflect principles generally applicable beyond the given objects. Such analytical investigations are here facilitated with different types of – semantically aligned – composite renderings of averaged profile data, which were developed by the author based on a preliminary analysis scheme.

In the *sorted view*, the 46 polarities are divided into three sets that correspond to “classes of subjectivity,” and ranked by absolute value within each set (Fig. 2). The first class of subjectivity contains qualities that predominantly describe formal, i.e. relatively objective and judgmentally neutral, properties. Antonym pairs that relate cultural (collective) or personal (individual) assessments delineate the profile in the second and third classes. The ranking of polarity values brings the most characteristic qualities of the building to the top of each class. Since the values rendered are an average of the polling data, the strongest differentials are a result of agreeing data sets and therefore of special significance. Neutral differentials may reflect either conflicting or generally indifferent assessments with respect to the given polarity; in either case, the identified quality would not be considered particularly characteristic.

The *standard view* shows the polarities grouped according to semantic similarity, whereby each group contains a set of antonym pairs of synonymous or closely related meaning. Since the layout is the same for all buildings, this is the most useful visualization for comparing and contrasting profiles of different buildings (Fig. 3).

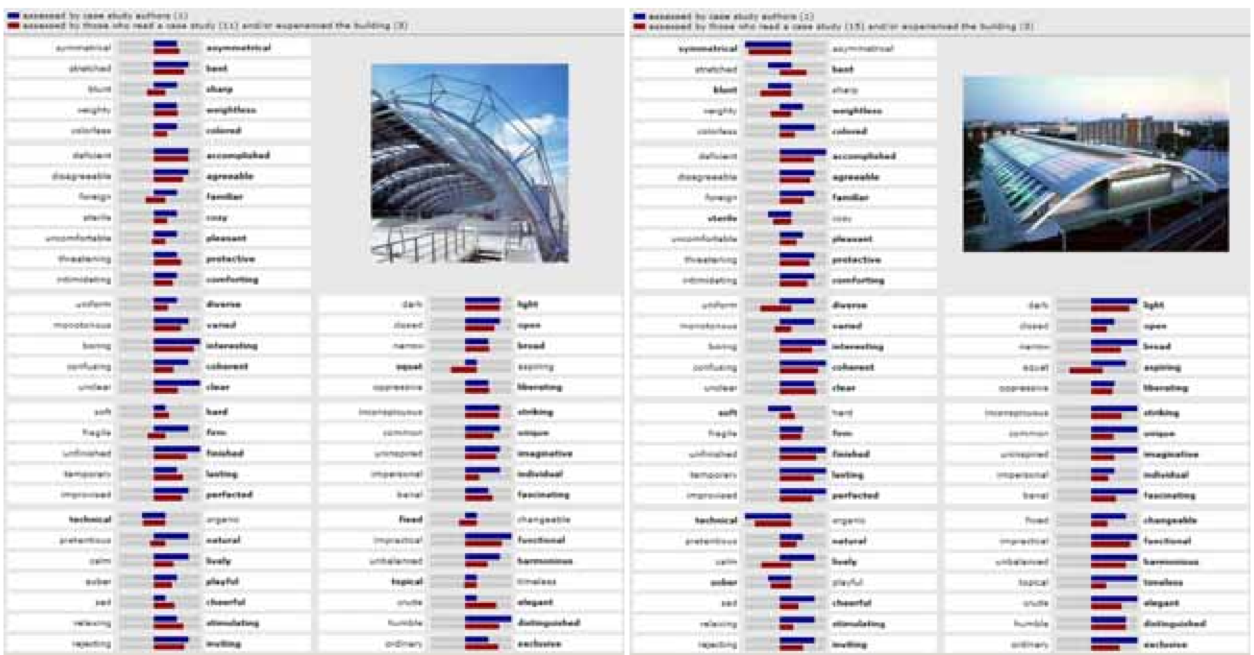

Figure 3: Comparing the standard views of composite polarity profiles for two buildings.

With the aim of internationalizing as much *archistructura* content as possible, the polarity profiles are currently being generated and presented in both German and English versions. Of course, a number of the original German expressions cannot be exactly matched to equivalent expressions in other languages, which inherently makes both the results (generated in part from translated data) and the alternate language views somewhat less precise than they would be if kept within the semantics of a single language. The given grouping does, however, compensate for this problem in as much as nearly every quality is circumscribed by the meanings of a number of “almost synonyms,” which in total – even with the inclusion of translated data – yield a fairly good and semantically comparable overall profile. The extensive data collected to date also shows that the inherent subjectivity of the polling process itself accounts for a much wider variance than subtle differences in the translated meanings of specific antonym pairs.

Moreover, the simplification process inherent to analysis removes the gradients in the original data by reducing it to encompass only characteristics that can be expressed in binary terms (e.g., a building is either one thing or its opposite, but not both at once, and not neither the one nor the other). Characteristic semantic dimensions can be filtered out of the established classification (meta-)data as well as from the polling data for a building. Working with “flattened out" binary values allows semantic coordinates from different fields of reference (e.g., structural morphology and perceived experiential impact) to be combined and related systematically. The general principle is illustrated by drawing information from three buildings in the collection, which, at first glance, have a number of general features in common (see legend in Fig. 4, left):

- *country* = European.
- *structural type* = large span structure.
- *primary construction materials* = steel, glass.
- *function/occupancy* = public.

This apparent similarity is also reflected in a wide-ranging set of common characteristics, expressed as binary polarities in agreement for all three buildings in the example:

- *structural/morphological* = linear, curved.
- *psychological/architectural* = accomplished, agreeable, protective, diverse, varied, interesting, cheerful, stimulating, inviting, light, liberating, striking, unique, imaginative, individual, fascinating, distinguished, exclusive, technical, comforting, clear, firm, broad, functional, elegant, coherent, finished, lasting, perfected, natural, harmonious.

Partial agreement is given on the following characteristics, which apply to two of the buildings without being contrasted in the third (neutral value): colored, timeless, open, bent, lively. Of the contrasting characteristics, only the polarities that apply to all three buildings are identified as key facets for the given comparison and summarized in a characteristic matrix of ordered 1's and 0's, e.g.:

polarities		building objects		
0	1	609	614	616
symmetrical	asymmetrical	**0**	**0**	**1**
sober	playful	**0**	**1**	**1**
cable (tension)	arch (compression)	**1**	**0**	**1**

Such *k*-tuple matrices can also be treated in the form of graphs and diagrammed accordingly as *k*-cubes with a theoretically unlimited number of semantic dimensions (cf., Bondy & Murty 1976). Given the spatial understanding of building designers, it makes cognitive sense to support the interpretation of up to three dimensions by visual analogy to the x/y/z/-coordinates of space (Fig. 4). A fourth dimension may be integrated either by adding a time axis to form an animated diagram, or by relating the surfaces of a tetrahedron to their opposite vertices.[2]

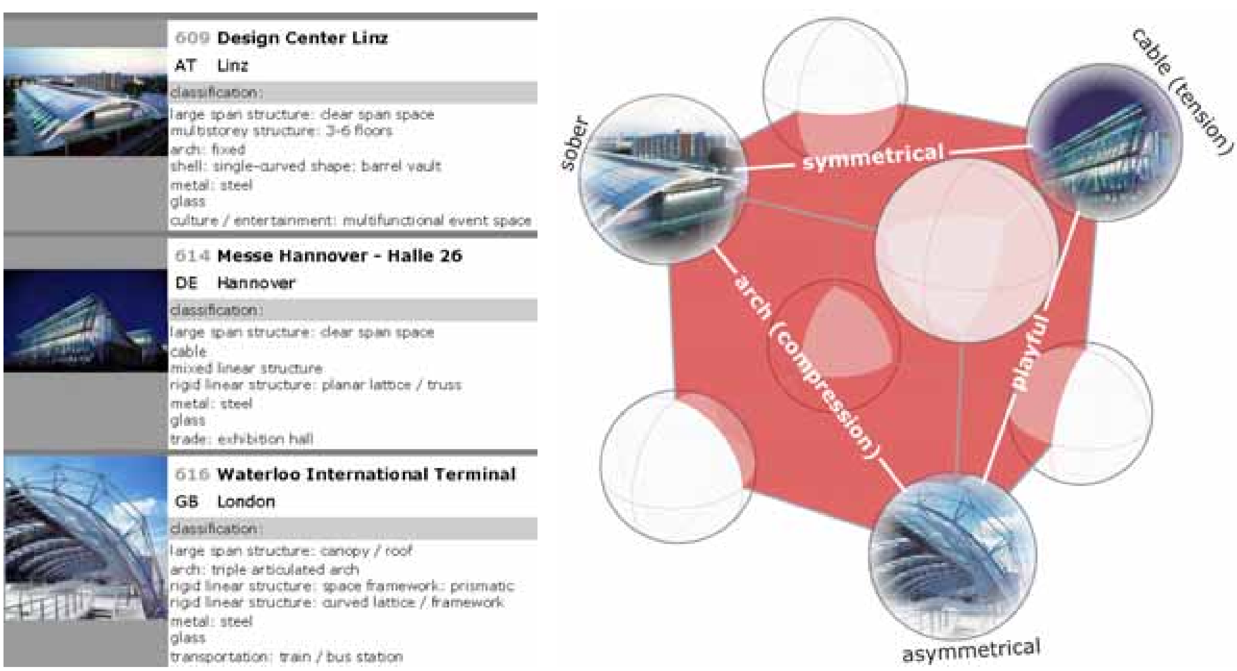

Figure 4: Analyzing common and distinguishing characteristics of three comparable buildings using a three-dimensional semantic cube.

[2] Including more than four dimensions in one diagram is generally pointless, since these can hardly be grasped simultaneously.

3. Application Stages and Results

The technical means for implementing the application concept for case studies in the building collection have been developed and tested in the context of several architecture courses carried out at the author's institution. 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 (Pfeiffer-Rudy & Jaksch 2004). As an intermediate format for weakly structured data, the *extensible mark-up language* (XML [3]) is especially well-suited for a number of well-documented reasons (Davies et al. 2003). Using a so-called XML publishing framework (Cocoon [4]), HTML pages are automatically created from the database content and published via a web server.
The courses themselves were re-designed and more thoroughly documented to better support integration in the online learning resource system. Course execution is accompanied by the submission of polarity profile data that, depending on the curricular context, reflects one or more of three related types of assignments:

a) building reviews in conjunction with a case study,
b) secondary building reviews based on existing case studies, or
c) direct building reviews.

Subject to editorial approval, polling data obtained from the respective reviews are used in the calculation of average polarity values and reflected in the profile visualizations upon the next publication update. Editorial monitoring tools were also developed to facilitate the identification of data sets that could significantly corrupt the resultant profiles (e.g., redundant submissions, obviously false statements, etc.), as well as to document student participation in the reviewing activities.
A brief description of how the different assessments were applied in the related coursework follows.

3.1 Building Reviews with Case Studies

Most of the courses that yield the main case-based data in the building collection focus on the system analysis of a building's construction in terms of its physical and technological characteristics. The primary thrust of analysis work in such courses lies in developing meaningfully structured, three-dimensional CAD models. To ensure that case study results may be communicated to others and the final data consistently imported into the XML database, the course work must furthermore be completed with a full report, which relates the most relevant information about the building, and documented in pre-formatted "workbooks" (Excel® files, see also Pfeiffer-Rudy & Jaksch 2004).
The report workbook includes a polarity profile worksheet for capturing the impressions that the case study author has of the building – as an "expert," so to speak, given the knowledge gained by thorough analysis. The act of filling out this worksheet also encourages the author to step back from the technical-analytical view and reflect the object of his or her case study in more holistic, architectural terms.

3.2 Case Study Reviews

At the beginning of a course of the type described above, participants are given an introductory assignment to review a set of case studies stemming from previous courses. The profile data in this instance is submitted via web forms (Fig. 2), which include a field for comments. The purpose of this introductory assignment is three-fold:

- to familiarize students with what will be expected of them in the course of the semester,
- to motivate students to think critically about what constitutes a truly informative case study, and
- to obtain additional feedback on the quality of the case studies from engaged, yet impartial readers.

The last point has also proven invaluable for detecting mistakes in the web-publishing framework and consistently improving the quality of information services provided.

[3] More about XML: *http://www.w3.org/XML/*
[4] More about the *Apache Cocoon* web development framework: *http://cocoon.apache.org*

3.3 Direct Building Reviews

The context of study trips, where students see and experience buildings first-hand, poses a natural application area for semantic differentials in their original meaning (see previous section on “Semantic Differentials and Polarity Profiles”). The methodology is employed to enhance the “usual,” that is, generally passive reception of toured buildings by encouraging students to reflect what they have seen on site (with paper worksheets) and afterwards (online) in semantic – rather than purely photographic – terms.

Such direct building reviews also provide valuable data to *archistructura* editors when checking the consistency of case studies and their reviews by comparing the resulting polarity profiles.

4. Summary and Prospects

At present, more than 300 buildings have been incorporated in the *archistructura* database, of which approximately half have been treated by students in the form of in-depth case studies with polarity profiles. Courses spanning six semesters have been carried out in a manner that integrally involves students in the knowledge generation and management process. Such fundamental measures as publishing students’ work and monitoring their active participation by the relatively simple and didactically responsible means of semantic differential assessment have not only significantly increased their motivation, but also markedly improved the overall quality of their work (as can be traced through the generations of case studies published to date).

At the outset of development, it was expected that the initial set of semantic polarities used in polling would eventually have to be updated and adapted to allow more precise translation for internationalizing the *archistructura* environment in general, and polarity profiles in particular. But as it turns out, the actual value of semantic differential data lies not so much in the validity of absolute results as in the didactic benefits of employing the methodology as such to accompany the process of teaching architecture.

As the data maintained in the building collection grows to statistically relevant dimensions, the developed tools shall be enhanced to allow interactively defined views of polarity polls. Useful in-depth renderings may include, for example, options to show the scatter of polling data or differentiate direct from indirect (case study) building reviews.

Functions to allow users to search the database for buildings with certain characteristic qualities, be they structural/morphological or psychological/architectural in nature, shall also be implemented in future releases. Finally, the type of multi-dimensional analysis described in section “2.2 Interpreting Polarity Profiles” should some day be facilitated by the implementation of algorithms for distilling and visualizing semantic characteristics in interactive, spatial diagrams (e.g., semantic cubes and tetrahedrons, hyperbolic trees, etc.).

In other realms of the *archistructura* project, “design-decision ontologies,” which incorporate multiple levels of building information in a semantic net of decision-related design criteria, form the basis for developing an educational design support system using Semantic Web technologies (cf., Davies et al. 2003). To this end, the set of largely technical classification systems currently formulated in the building collection of *archistructura* shall be extended to cover a number of ontologies that are more directly architectural and design-related in nature (such as pattern languages, cf., Alexander et al. 1977). The approach taken for prototype development to date is that of staking out potential scenarios for design-decision sequences in order to characterize and systematically interweave threads of related design criteria. Such multi-dimensional ontology maps should serve to point up the information needs that arise in the course of individual building design paths so that they may be met more effectively by the projected decision-support system.

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