Comprehensive Visualization for Architectural Material Selection

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Abstract

The condition of information overload has become a common problem in the construction industry and has resulted in a critical need for the development of "intelligent decision support" systems. Material selection occupies a precarious position within this discipline because of the addition of complexity brought about by new and more advanced materials that have become available to designers. The strategies outlined in this paper allow a designer to visualize not only material qualities and behavior characteristics, but provide the means to distill, organize, and select relevant data. The decision matrix is defined by multiple disciplines, incomplete and varied information, and an explosion in the production of materials that have dynamic properties. Emphasis must be placed on distilling and presenting critical information in a comprehensive and visually accessible format.

Materials pervade our lives. We interact with them on many levels throughout our existence. Materials are what we wear, what we touch, what protects us on a daily basis, and what shelters us where we live. The history of civilization is broken into time periods based on materials; the Bronze Age and the Iron Age, to name a couple. These time periods imply that it was not homo sapiens that evolved, but instead their material knowledge and their ability to transform this knowledge and technology. Currently civilization is at a stage where many disciplines are at a point of convergence. Biology, engineering, material science, and computing are all working in some relationship to material production. This disciplinary convergence has brought about an explosion of new materials in the construction materials marketplace, making the materials selection process more complex than ever before.

The primary barrier to implementation of new materials is that their benefits can not be easily communicated to the people responsible for material selection and eventual application. Many resources and databases exist to aid designers in selecting materials by making material data plentiful. Unfortunately none of these databases make the data completely usable, or present a strategy for selecting or comparing materials both comprehensively and visually in response to the conditions and needs of the construction industry.

It is important to locate this research on the material / property curve to understand the relationships that are influential in the material selection process. This curve depicts the design process, early on, a designer is concerned with many materials with a couple properties. As the design process proceeds the concern shifts to understanding a few materials completely. This research begins at the central point on the curve because this is where a comparative strategy is the most appropriate, figure 1. The top end of the curve can be characterized as so intuitive and broad that it does not need to be visualized. Most decisions at this level are made based on experience and the designer's intent. The opposite end of the curve is very specific and moves into the realm of prototype testing and simulation strategies. Here the study becomes very specific to the project. Issues related to geometry, orientation, and compatibility cannot be answered by a database but only through physical testing.

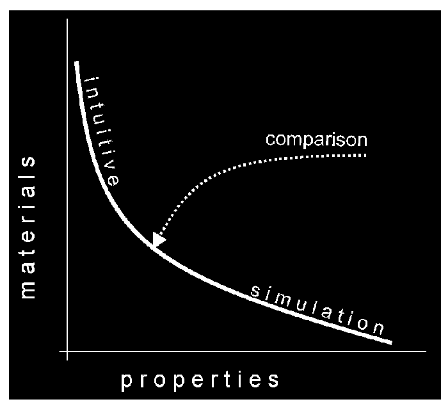

figure 1 - Diagram of tasks overlaid on "materials vs. properties" plot of the material selection process

The properties that a designer would be interested in when making a design decision have multiple consequences throughout the material selection process. An early realization was made that the material selection process depends on who will be making the decision, after all, the act of building is a multi-disciplinary endeavor. Designers are important but they are not the only people involved in the creation of a built project. Clients, builders, designers, and consultants all play critical roles in the decision making process. The interests of these groups was used as an organizing factor in the development of the diagramming strategy, in which lobes are used to group related types of data.

Thus, the problem becomes more complex: how to compare different materials, using multiple parameters, based on different and often conflicting criteria. The need for a visual and comprehensive strategy for data presentation developed in response to the dynamic qualities of the design process, the diverse users involved, and the constantly evolving material data. The goal was to created a simple, inclusive, and diverse framework to present the information.

Data Acquisition

Early in the development of this strategy it was necessary to create a small but comprehensive database to explore the methods with which architects gain material knowledge. This initial activity simulated the task one might carry out in an architectural office. Glass was selected to focus the research because of its level of complexity and many new innovations in the industry. All of the products would have to be represented by a comprehensive range of physical properties and behavior specifications. It was soon realized that the idea of a fully comprehensive database was unattainable without automating the data acquisition process. The major problem associated with the graphic representation of this data would be the representation of its reliability. It would be necessary to communicate the level of confidence in the data, depending on the reliability in the source of the information. A second aspect associated with data acquisition (or the lack of it) would be the representation of missing data. The missing data resulted from the time required to interact with product representatives and search for, or obtain comprehensive data from manufacturers. Usually manufacturers will only advertise the information that makes their product different from other products, or superior to other products, as opposed to a comprehensive listing of its composition.

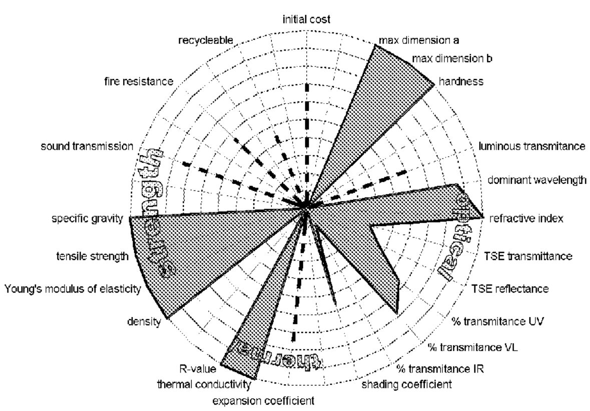

figure 2 - Diagram with inclusion of "grey data"

An important innovation developed around the relationship between the gaps in the database and the visualization of the diagram. Designers must be ready and able to work with an incomplete set of data, since this is the present situation. This condition raises the issue of "grey data"(Olsson, Bengtson, and Fischmeister 1980). Grey data is data that is assumed or inferred and is not taken to be exact. It is data that has been inserted as a "place holder". Grey data represented on the diagram must be clearly flagged allowing the designer to understand its un-validated nature. Figure 2 shows a diagram that contains grey data. The designer has the option to leave the data blank, or fill in the gaps with values based on experience. The diagram shows how this grey data may be represented by broken lines, making it clear that the value is different from the accepted values in the database.

A common misunderstanding is that engineering is an exact science due to the importance placed on quantifying and validating information. It was with this understanding that the material selection system was initiated with an emphasis placed on exact numbers for the database, however values are typically multiplied by safety factors. With this understanding, the emphasis shifted to permitting ranges of data ,as opposed to exact numbers, allowing designers to arrive at more realistic material judgements.

The following diagram, figure 3, for lead glass illustrates ranges of values resulting from the production process and chemical composition. These conditions can have dramatic effects on the performance of the glass resulting in a wide range of values. An example of this range can be seen with the property of *density* which varies between 3.03 to 6.22 g/cm^3.

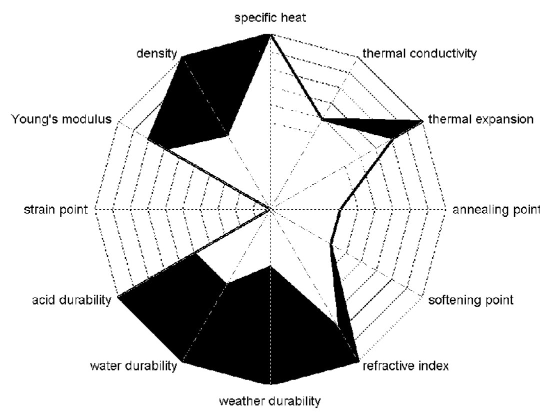

figure 3 - Ability of diagram to visualize ranges

Process Responsiveness

An important aspect of this research is that the visualization strategy must be sympathetic to the design and material selection process. The material selection process is not something that is commonly made explicit in the realm of architectural design because most designers understand it as simply choosing a material. This condition has already begun to evolve because as complexity increases the simple act of selection will grow into a specialization. The material selection process is seen as an assessment of material options concluding with the specification of a material. The final activity related specifically to materials - repair - usually occurs when something goes wrong, providing a certain level of feedback for designers. By understanding this process, the material selection diagram can respond to the various needs and become useful throughout the process.

The main difficulty in the creation of a material database and visualization strategy for the construction industry is that it needs to be accessible to a wide variety of people whose needs and knowledge are at a number of levels. Because the process has such a varied amount of activities, the data must be responsive to these variations. Two scenarios exist: the first is using the database for the duration of the material selection process; the second is accessing the database at a very detailed level in the material selection process.

The following diagrams, figure 4, illustrates the ability of the visualization strategy to respond to the varying complexity of data associated with the material selection process. The example responds directly to the assessment / specification activity of the selection process. Based on the material / property curve, it demonstrates the ability of the visualization method to aid in the navigation and selection of materials when starting with many options. As the material options become more focused, the level of detail increases and becomes more material specific. The initial search can be navigated horizontally beginning on the top level. As glass is selected, a jump is made down to a more detailed level of information, where a comparison is again made horizontally between types of glass. As a glass type is selected, again a jump is made down to a more detailed level of data, permitting increased detail of glass properties. The database / diagram relationship allows for a progression from horizontal movement (comparisons) to vertical movement (increase or decrease in detailed information). As the list of general materials is narrowed, the amount of properties can be increased in an attempt to provide a more comprehensive understanding of the performance of the materials. In this case “glass” is selected to explore options within this family. Five types of glass are presented with a list of properties that are applicable at this point in the process and to this group of materials. “Fused silica glass” is selected because of its superior mechanical properties: strain point, annealing point, and softening point. This decision presents four more specific types of glass that are found in the fused silica glass family.

In addition to the material selection system acting as a navigational device, it can also serve as an organizer of diverse types of data, incorporating multi-disciplinary information and organizing it in a clear and intuitive fashion. Similar to the previous example, an interactive navigational strategy is created that aids in the organization the data. An upper level of information of more general data may be organized by disciple. The user can explore the rationale for the overall mapping of the material by selecting the specific disciplines - such as structural, optical or thermal. As the design progresses or as more specific information is needed, the designer can explore additional aspects related to the material by “clicking” on the discipline - in essence interrogating a deeper level of data contained within the diagram. Selecting “optical” may present the user with a similar looking diagram, but it may be composed of properties specific to optical characteristics of glass. Moving deeper into the diagram by selecting one of the terms used to present optical properties such as transmittance could take the user to a simple simulation program where the material can be radiosity rendered. At a higher level, clicking on “constructibility” may present the user with a case study of a project under construction. The material selection graphic, in this case, organizes and presents vari-

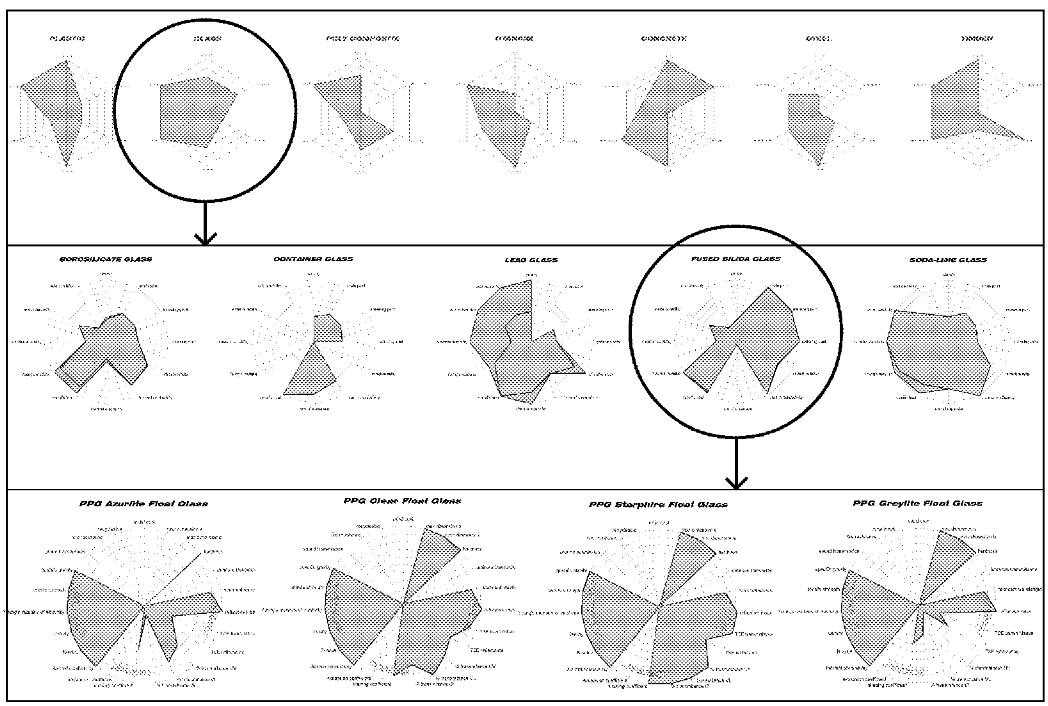

figure 4 - Material selection diagrams offering navigational structure

ous types of information that can be presented in various visual formats that respond more specifically to the information of a discipline.

User Interaction

One aspect of the material selection diagram that shifted the research from that of a passive visualization technique to that of an interactive system was the ability for a user to input design parameters. This input would become not only a way to interact with the graphic but an opportunity to reorganize the presentation of the data.

By asking the designer to input the values of properties that should be attainable by a material, a design profile is created. The goal then is to find a material that most closely matches the design profile. In most cases, the design profile will evolve over the duration of the design process, arriving at a refined material selection at the conclusion (Olsson, Bengtson, and Fischmeister 1980). Initial assumptions are made, tested, and refined. As more information is available, more refined decisions can be made. This process then concludes with the selection of a material.

The design profile can act as a secondary layer of information that is the input from the designer. A material with a property below the design profile may not a viable option for the designer. Similarly, a material that far exceeds the design profile may also be considered an un-viable option based on economics because a premium must be paid for the high performance. The designer then needs to either think about refining the design profile or fine tuning the material choice to a material that more closely reflects the design profile for that specific application.

The design profile also becomes the search criteria for the system to find appropriate material choices. The user can specify a viable range based on a percentage of how close material properties must match the design profile. These variables have the ability to be specified for each material property. Some properties are critical and need to be met exactly, whereas other material aspects can have any value and do not effect the criteria of the selection process. The user would have the ability to input a range of the properties for the material, such as a maximum and minimum value. The user is also able to reorder or add a weighting to properties that are important for a particular project.

The design profile also offered an aspect to the graphic quality of the diagram. The material values can be seen as static elements because they represent the materials, which do not evolve over the course of the design. In contrast, the design profile becomes a highly dynamic and interactive aspect of the material selection process. This line then becomes an overlay with which to reference the material properties. The design profile was successful in that it provided a datum when comparing one material to the next, providing the user with a reference point to judge the perceived effectiveness of the material, see figure 5.

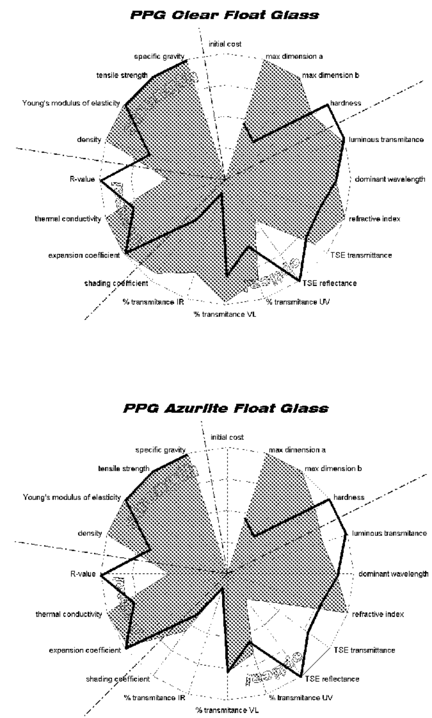

figure 5 - Two materials that are compared with the use of the design profile as an overlay

Extending the visualization based on the designer's profile is provided by reorganizing the material information based on the values input by the user. This operation can be understood as a filter that presents the material data in a new configuration. The following example, figure 6, presented with a profile-centric operation makes use of the same data as figure 5, the only difference is the way the information is visualized.

The design profile becomes a circle that represents a benchmark. The material values are then compared to the specified values and a percentage is calculated. This type of profile centric representation proved to be easier to understand visually because it eliminated the complexity created by the competing lines of the material properties and the design profile. This visualization strategy makes the profile a simple circle and allows the user to concentrate on the relationship between the properties and profile. In contrast to the previous example where the properties of the material do not change from one application to the next, this profile-centric operation alters the profile for each application, creating a specific, custom diagram for each design application.

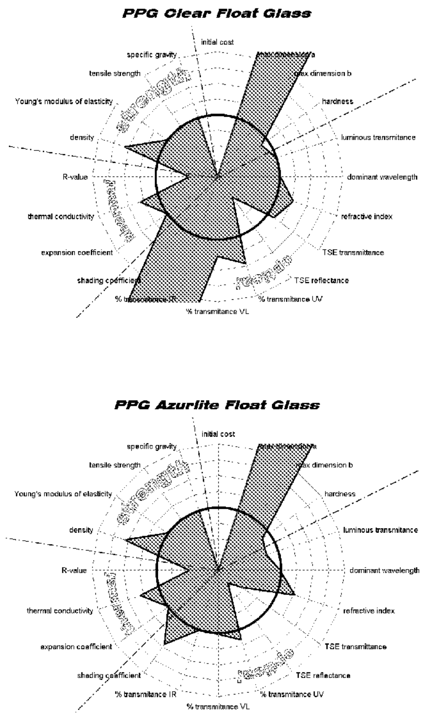

figure 6 - Two materials compared using a profile-centric visualization strategy

Conclusion

The material selection strategy presented in this paper is the result of the convergence of research in design processes, construction material technologies, and visual representation. When dealing with a topic that connects multiple fields, the evaluation process must also adopt a multi-disciplinary focus. The flexibility exhibited by the material selection process is a direct result of the strategies being pushed by user demands that are varied and diverse. The user is not only permitted to customize the interface, but in so doing they are customizing the work process. The choices made regarding visual and graphic results, had effects on the underlying organization and data manipulation and vice versa. The strategy that is responsible for the material selection diagram was not only responsive to the diversity of the disciplines involved but used the influences as generators during the design process.

References

Cardwell, Cather & Groak. "New Materials for Construction." *The Arup Journal* vol 32 no 3 (March 1997): 18-20.

Olsson, Bengtson, and Fischmeister. 1980. Computer-Aided Materials Selection. In Proceedings of Computers in Material Technology Conference, Linkoping University, Sweden.

Wigginton, Michael. *Glass in Architecture.* London: Phaidon Press Ltd. 1996.