

5

data synthesis

A Comprehensive Visual Approach to Material Selection in Architecture

by Karl Daubmann

BArch 1995
Roger Williams University

Submitted to the Department of Architecture
in Partial Fulfillment of the Requirements for the Degree of
Master of Science in Architecture Studies
at the Massachusetts Institute of Technology

June 1999

©1999 Karl Daubmann, All rights reserved.

The author hereby grants to MIT permission to reproduce and to distribute publicly paper and electronic copies of this thesis document in whole or in part.

Signature of Author _____

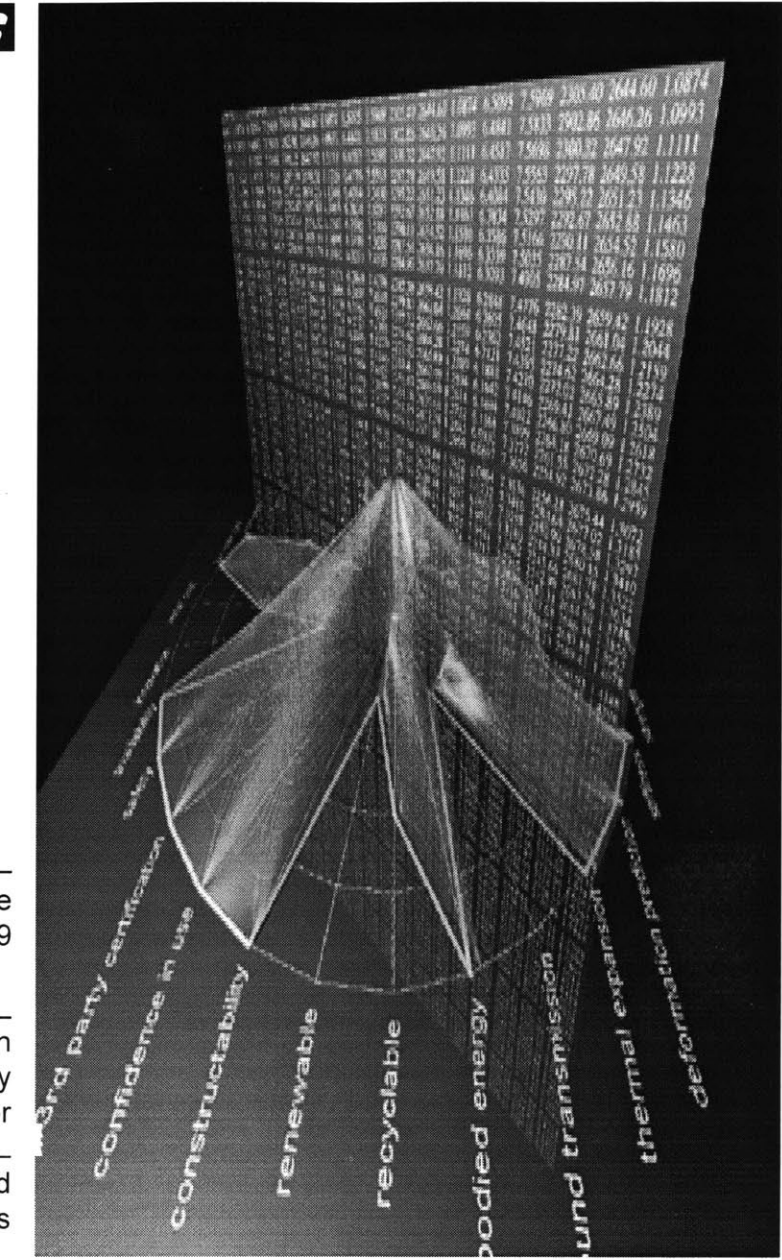
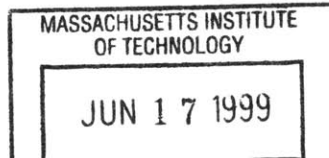
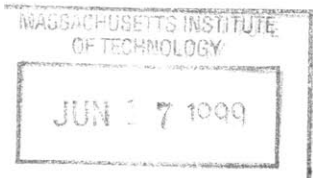
Karl Daubmann, Department of Architecture
May 20, 1999

Certified by _____

Dr. Chris Luebke
Assistant Professor of Building Technology
~~Thesis Supervisor~~

Accepted by _____

Roy Strickland
Chairman, Department Committee on Graduate Students



ROTC

data synthesis

A Comprehensive Visual Approach to Material Selection in Architecture

Thesis Reader _____
William J. Mitchell
Dean, School of Architecture and Planning

Thesis Reader _____
Anthony Sheehan
Materials Scientist, Ove Arup and Partners R+D

data synthesis

A Comprehensive Visual Approach to Material Selection in Architecture

Karl Daubmann

Submitted to the Department of Architecture on May 20, 1999
in partial fulfillment of the requirements for the degree of
Masters of Science in Architecture Studies

ABSTRACT

The condition of information overload has become a common problem facing contemporary designers. This has resulted in a critical need for the development of "intelligent decision support" systems. One such system would allow a designer to visualize not only material qualities and behavior characteristics, but provide the means to distill, organize, and select relevant data. Material databases and the enabling power of the internet can only be exploited as "information providers" for designers when such a system is adapted. Material selection has been identified as a means of exploring this type of analysis / assessment strategy because it is a specific activity (within the broader realm of design) that is concerned with complex decision making processes. 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 accessible format.

Thesis Supervisor: Dr. Chris Luebke
Title: Assistant Professor of Building Technology

table of contents

1.0 INTRODUCTION	5
2.0 SYNTHESIZING DATA	9
2.1 Traditional Data Resources	
2.2 On-line Data Resources	
2.3 Comparative Methods	
2.4 The Diagram	
3.0 TEST CASES	23
3.1 Data Acquisition	
3.2 Process Responsiveness	
3.3 Inclusive Strategies	
3.4 New Materials	
3.5 Collaborative Design	
3.6 Designer Input	
4.0 CONCLUSION	62
5.0 APPENDIX 1 - Presentation Boards	64
6.0 LIST OF ILLUSTRATIONS	71
7.0 BIBLIOGRAPHY	74
7.1 Analysis and Visualization	
7.2 Materials	
7.3 Glazing	

Note: All photos and illustrations have been prepared by the author unless otherwise noted.

1.0

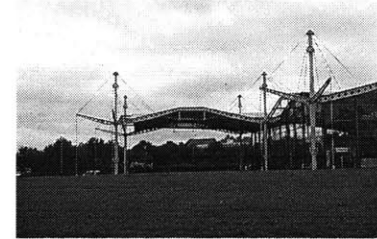
introduction

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, 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. 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.

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. The most extreme contemporary example is the newly developed organic computer chip. This convergence of disciplines has also brought about an explosion of new materials in the construction materials marketplace. These materials are far more advanced in many ways than the materials that have been traditionally utilized. This makes the materials selection process even more complex. The main problem creating a barrier to implementation of these new materials is that their benefits can not be easily communicated to the people responsible for material selection and eventual application.

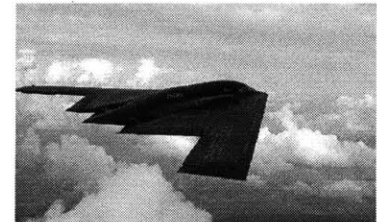
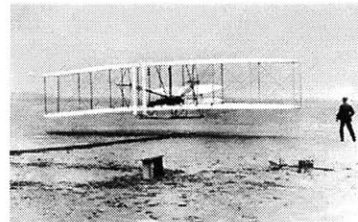
The challenge now is to find appropriate applications for the new materials and technologies. Design and production are at a point in history where primary concerns can be implemented easily by designers. This allows them to concentrate on solutions that can be optimized for multiple design parameters and requirements. One such example is found in aviation. The daunting challenge which faced the Wright Brothers in 1903 was to create a flying machine (see fig. 1.3). At that time, this was no small task. Flying was the primary requirement. Today it has become trivial to design a "flying machine". This could be considered at best a secondary requirement, if not tertiary or less. Other issues, not remotely related to flying, have now become of primary concern. The B2 bomber (fig. 1.4) is not a plane known for its high aerial acrobatic or speed performance, rather for its invisibility to radar.

Architects also have the opportunity to innovate if they respond to a similar reconsideration of primary and secondary design priorities provided by new materials. One reason for the emergence of innovations is based on an increasing design space. The origin of construction was to provide shelter which could resist the elements. Today, it would be very rare that a client would ask an architect simply for a building that provides shelter. Architects must understand what this increased



1.1
1.2

new materials yield new opportunities

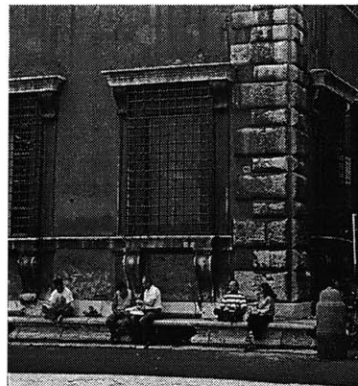


1.3
1.4

photo from National Air and Space Museum, Smithsonian Institution, Washington, D.C.

photo from USAF by by MSgt. Rose Reynolds

expanding design space



1.5
1.6

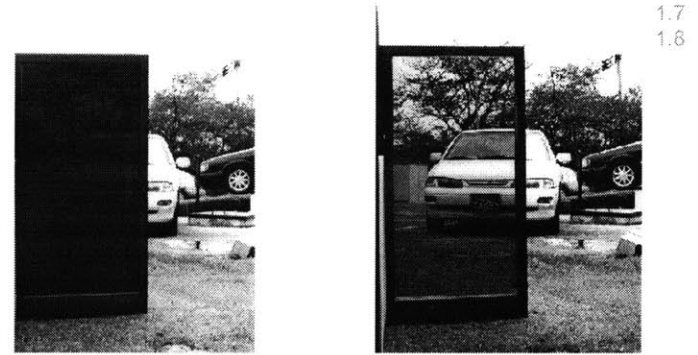
architectural implications of building materials

design space means, and how it can advance their work. “Invisible bombers” are a reality because the right materials and technologies were used in response to a difficult requirement. The problem becomes the management of this information, making a beneficial link between materials and applications.

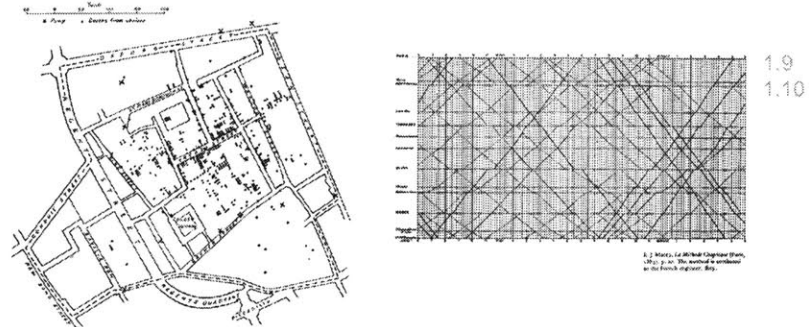
The recent debate about “smart materials” has elevated the discussion of materials in the construction industry. These materials are able to sense change in the environment and change a property in response. Because these materials are still new, they are costly. And since they are costly, clients are too often reluctant to pay the premium for their use. However, by plotting their properties in a clear and concise manner, one can begin to understand that the advantages of their use outweigh the prohibitive costs.

Visualization

Graphic representation is one strategy able to relate all of the various disciplines and data types involved in the construction process. There is a history of visual representation illustrating complex information in simple and abstract terms. One example is a map of London (fig. 1.9) with dots marking deaths caused by the plague, while the crosses represent water fountains. By geographically mapping the locations in two dimensional space, one can see the distribution, and as a result formulate an understanding of the relationship between the water supply and the spread of the epidemic. The information could be described in text or numbers but would be incredibly complex. The second example is a French train schedule (fig. 1.10). At first glance it appears very complicated. By charting the arrival and departure times of trains, one can see very clearly that a steep slope on the graph means a faster train. One can also see the duration of “lay overs” at different stations. A viewer can interact with the graphic by studying it, asking specific questions of it, finding answers, revising the question, and finding more detailed answers. This example of the train schedule shows that a visual representation can not only present data, but it can organize it and make it understandable and usable.



transparency can be altered with SPD glazing (suspended particle device)
photos from Research Frontiers Incorporated



historical examples of visual representation
1.9 (E.W. Gilbert, “Pioneer Maps of Health and Disease in England”, Geographical Journal, 124 (1958), 172-183.)
1.10(E.J.Marey, *La Method Graphique* (Paris, 1885), p.20)

The Design Process

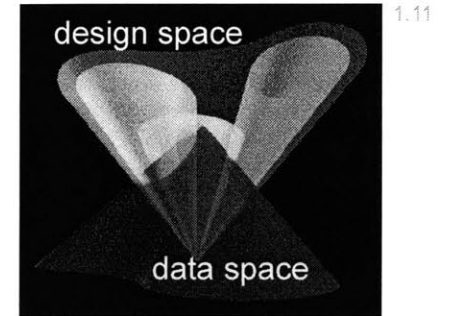
The first quality of design that needs to be understood is that it is a process. It changes. Design typically moves from a very broad exploration to a specific investigation at a detailed level. The design space decreases as the design is refined, while the data space or information that is known about the design increases (fig. 1.11). An example of the increase of design data can be seen with the design of a simple wall. In the beginning, the wall may be opaque or transparent. As the process continues the wall may be glass with specific thermal and visual qualities. Therefore, early in the process the wall can be anything, later in the process the parameters of the wall are very specific.

Architecture is a field that must confront converging disciplines on a daily basis - understanding relationships between science and the arts. One simple example is the description of sunlight. One could describe light in a quantitative way, using a chart of solar radiation values (fig. 1.12). This would very clearly describe the amount and intensity of sunlight. A more qualitative description that aims to represent the feeling of light in relationship to space and materials could be done with a painting, photograph, or rendering (fig. 1.13). This form of description would illustrate issues of the light's color, what the light strikes, and the patterns of shadows. Both qualitative and quantitative methods of description are necessary to convey the "entire story".

The Architect's Role

The construction process is another realm in which complexity is increasing. Organizational complexity results from fragmentation created by the increased specialization of the construction process. There are no longer craftsmen that design and build custom buildings. The craftsmen have been replaced by teams of designers, teams of builders, teams of technical consultants, there is even an increasing complexity in the ways that clients are representing themselves; usually with users, facilities managers, lawyers, and owners.

The architect occupies two critical positions in the strategic organization of the construction process. The first relationship is in building production where the client, architect, and builder have a contract to build a building (fig. 1.14). The architect has a responsibility to the other two parties involved and acts as a mediator and translator throughout the process. The architect must understand the client's needs



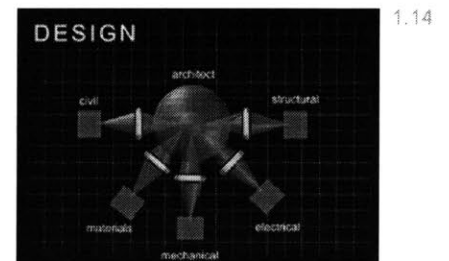
design space / data space



quantity



necessity of quantity and quality

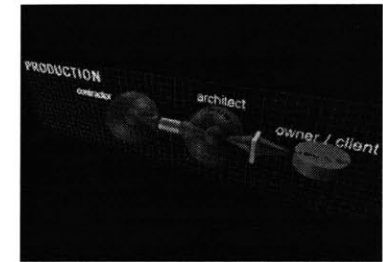


architect as integrator

and requirements in order to design a building. Fundamentally, the architect is translating the wishes of the client into terms with which the contractor can build. The second series of relationships is related to the design process, where the architect must put together a team of specialists that will act as consultants (fig. 1.15). In both sets of relationships the architect's role is to coordinate the varied activities. The architect is an interface or filter for the exchange of information from one party to the next.

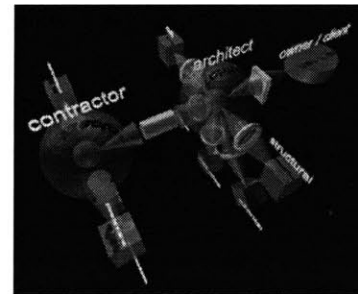
This organizational analysis demonstrates the complexity involved in this exchange of information. None of these groups speak the same language. The act of building is a multi-disciplinary one. Figure 1.16 illustrates the intersection of the design plane, production plane, and construction plane. The arrows of the diagram (fig. 1.17) then begin to show how information is communicated from one group to the next. These diagrams present the most generic strategic approach; as many variations exist. Another level of complexity (as if there was not enough already) is that these project relationships are different from project to project. It is virtually impossible to find any kind of rhythm from one project to the next because the next project will be formed with a new client, new contractors, and new consultants.

The materials selection process means something different to each one of these groups. Each has its own objectives and working strategies. The role of the architect as related to material selection is to translate the different issues and resolve them into one buildable solution.

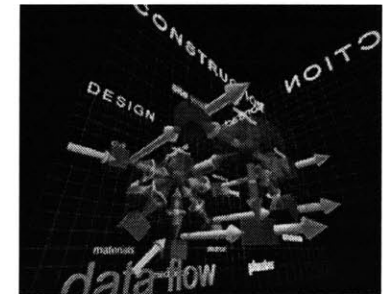


1.15

architect as integrator



1.16



1.17

construction process and data flow

There is a tsunami of data that is crashing onto the beaches of the civilized world. This is a tidal wave of unrelated, growing data formed in bits and bytes, coming in an unorganized, uncontrolled, incoherent cacophony of foam.

Richard Saul Wurman from Information Architects

2.0

synthesizing data

The thesis work has developed as the intersection of three areas of interest within the discipline of architecture. The first area was the way a designer thinks and makes decisions throughout the design process. The second area was the way in which information is visualized with graphic forms. And the third area of interest was the exploration of the material selection process that focused the investigation to a manageable scope.

A series of questions have been central to this investigation, and in all cases “information” refers to specific properties of architectural materials:

How do designers acquire information?

What information do designers want?

How should the information be organized and presented?

How do designers organize information once they have it?

How will the information be applied?

2.1 *traditional data sources*

The following is an analysis of the traditional methods through which architects acquire material information. The importance of looking at these resources lies in that they contain the information that architects have been working with for many years and provide a certain level of familiarity for designers. It is also relevant to investigate how designers obtain material information, the amount of time it takes to carry out the task, and the amount of effort that is necessary to acquire the information, with the goal of comparing materials.


Suppliers

The most commonly used resource for acquiring information about materials is the "Sweet's Catalog" which is updated every year. This multi-volume encyclopedia of materials and products is organized according to the "CSI master format", based on different trades involved in the construction process. The entries are by supplier with a listing of all the products that they offer. Typically these entries will be the literature provided by the suppliers. Sweet's catalog provides an enormous amount of information about materials and their properties, as well as contact information for more detailed inquiries.

Another very common method used by designers to obtain detailed information about a material is directly from a supplier. This is usually done by contacting a company and interacting with a representative. The "product rep" can act as a consultant for that specific material, providing samples, more detailed information, and information related to past experiences from a completed construction project. The problem is that representatives are not always available, designers must track them down and spend valuable time trying to get relevant information.

Periodicals

Designers also acquire material information from magazines and trade journals. There are typically two ways this happens: from projects in magazines and from "technology" sections that may highlight materials or products. The first method allows designers to see completed projects where a solution from another designer may have relevance to a project. A designer can then track down the type of material or the supplier and begin investigating the viability of that material for the project.



The technology sections of magazines focus on a type of material that is either relevant to the periodical theme or a common technical problem. The article will give background information for the material, what types of applications it has been used for, the parameters that make it special, and important aspects to think about during the design process. Usually many suppliers are included in the article to give designers freedom and options related to availability and cost. The technology sections also presents some form of case study to give designers a deeper understanding of issues related to the design problem, to issues of integration, and possible problems associated with installation. The reader is also given the name of the suppliers, allowing the designer to contact them for more detailed information.

Other Designers

Designers also rely on colleagues within their firm (or outside their firm), to gain information about materials and products from past experiences. It is not uncommon to hear someone say, “this person just completed a project with a similar problem, you should ask them how they solved it, or what material they ended up using”. This type of knowledge transfer is not very innovative but is a valuable method for a designer to build upon the knowledge of someone who has dealt with a similar situation. Usually within an office there is an individual or group of people who act as specialists on technical aspects, and build on knowledge related to detailing and construction issues.

Consultants

The last method available to a designer to gain knowledge about a material or product is through a consultant. This could be a consultant that specializes in materials or one that has information about materials associated with their discipline. This type of material knowledge acquisition depends on the size and scope of the project, obviously smaller projects will not have a budget that allows for specialized material consultants. Usually if such a material consultant is needed for a project it is because there is a problem, and the consultant is brought in to fix the problem. Had the consultant been involved in the project from the beginning, the problem may have been avoided completely. The ideal situation would allow the consultant to provide input during the design phases, allowing the designer and consultant to collaborate and build on one another’s experience.

2.2 ***on-line data resources***

Web-based Information

In order for designers to innovate, they must be able to access up-to-date information. One aspect of the research was to uncover the methods that are available for designers to access this type of material information. It became clear early in the project that this is not an easy task. There are two major categories of products or materials related to the construction industry, those commercially available and those under research and development. For the thesis it was decided to focus on commercially available materials with the understanding that the information would be more relevant to the issues that architects would be most concerned.

The exploration into web-based resources is founded on the belief that the web, because of its foundation as an information provider, has the potential to change the ways in which architects work. In order for this to occur the web needs to present advantages over the traditional methods through which architects acquire information. The two obvious benefits are that web information is easier to update than catalogs or other paper sources and that the information is already in a digital format allowing for manipulation and incorporation into drawings or specifications.

The following pages present a number of web-based databases that are available to designers. The databases were analyzed to uncover any common patterns that may have been developed for presenting information and to develop and understanding of how to organize and navigate what could amount to 20,000 materials.

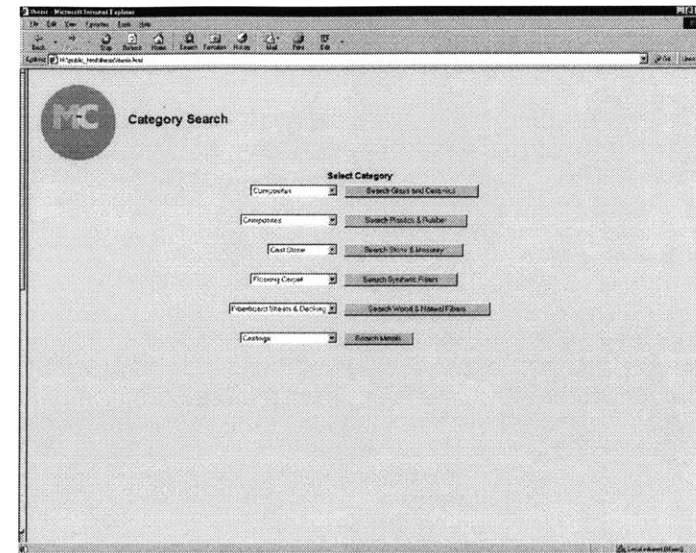
Note: the images that are used to present the databases are screen captures of the on-line databases and are labelled as "ss" for screen-shots. They have been taken from the webpages listed at the top of the page.

Material Connexion Database <http://www.materialconnexion.com>

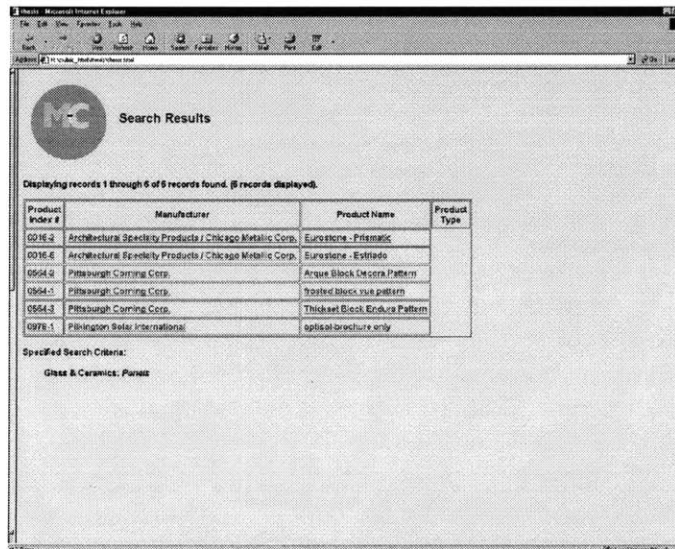
audience: architects, designers

The Material Connexion is a gallery / materials showroom that connects designers with material suppliers. They concentrate on the physical and qualitative aspects of materials by allowing designers to see and touch material samples in a showroom setting.

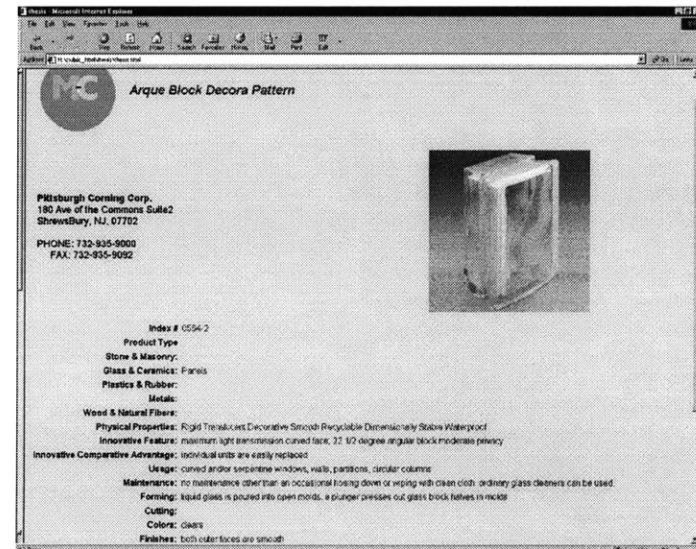
The screen-shots illustrate the navigation of their web database. The first screen breaks materials into predetermined major headings with subcategories. In this case, "panels" was selected under the "glass and ceramics" category. The result of this selection is seen in ss2.2. It is a list of product numbers, manufacturers, and product names. The materials can be found in the Material Connexion bin system using the product number. Selecting the "arque block decora pattern" brings the user to ss2.3 which displays supplier contact info, a photo, and a description. Unfortunately the description is very basic. In this instance, the material properties are stated as: rigid, translucent, decorative, smooth, recyclable, dimensionally stable, and waterproof. Clearly, if a designer is really concerned about the performance of the material, this database does not offer any significant level of technical information.



ss2.1 - view of the materials category search page



ss2.2 - view of a list of returned materials from a search

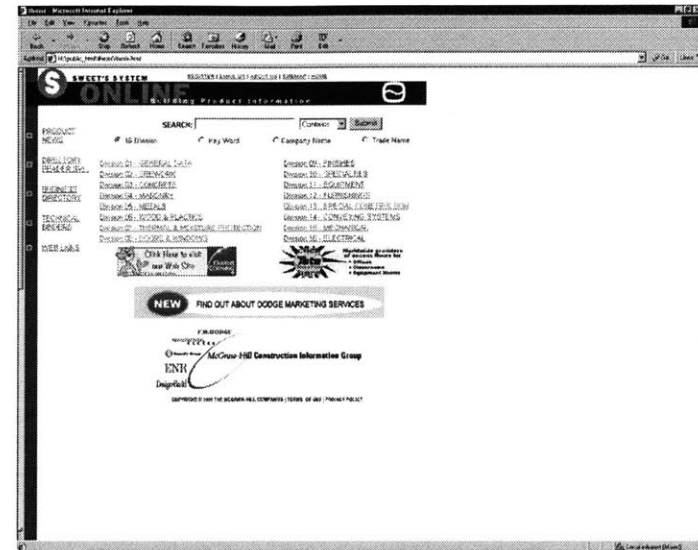


ss2.3 - view of a detailed information page

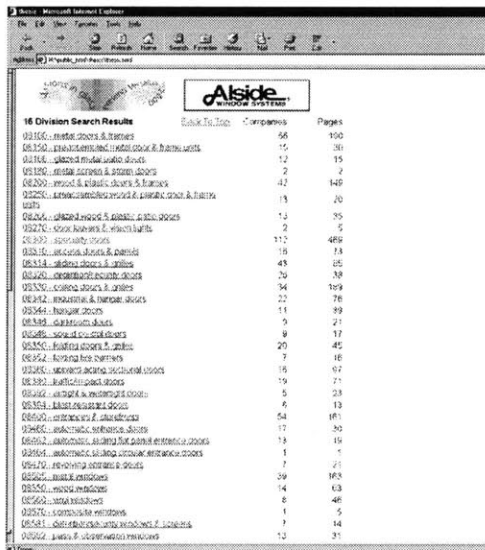
audience: construction industry

The interface developed for accessing information from Sweet's On-line is based on the CSI masterformat. The "search page" contains a list of the sixteen divisions of the format (see ss2.4). Selecting "Division 8 - Doors and Windows" brings the user to the next screen (ss2.5). The user is presented with a list of different sections within Division 8. Selecting "8300 specialty doors" (as one option) takes the user to ss2.6 which displays manufacturers with various products that fall under the 8300 heading. By selecting "single glazed windows" produced by Baut Studios, the user is taken to a page that presents information about the specific product; the company, size availability of the various series of windows, and in many instances, photos of the product.

The main drawback of this type of interface is that it is application and product driven. This database works well for a designer in the detail design, but does not aid the designer in the concept stages of a project. The navigation is linear and straightforward since it is designed to get the user to a specific bit of information in the shortest amount of time, without giving the user options along the way.



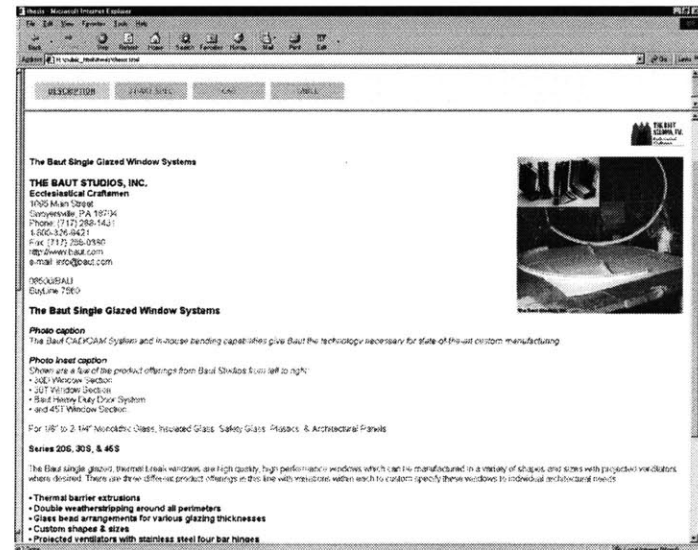
ss2.4 - view of the materials category search page



ss2.5 - list of returned materials from search



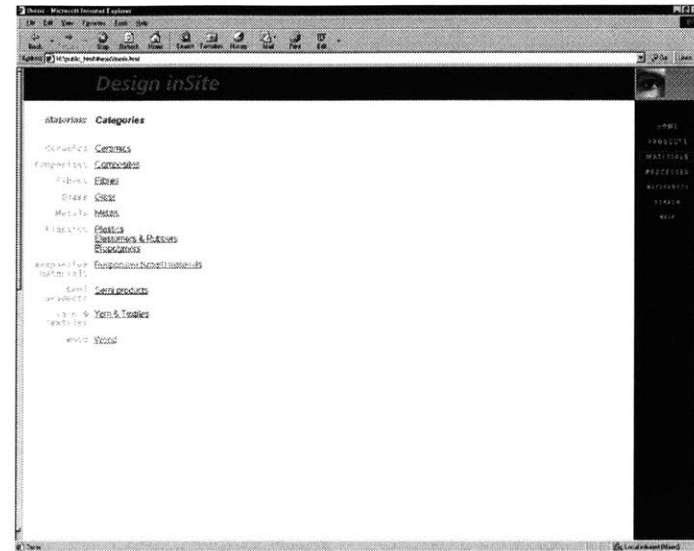
ss2.6 - list of returned products



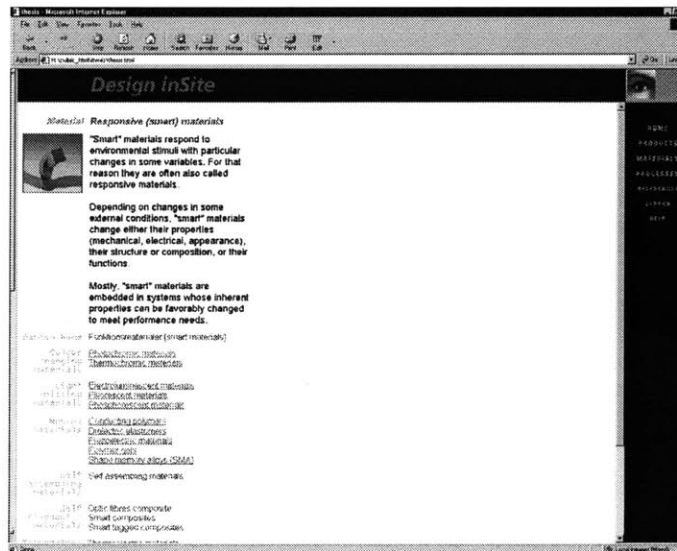
ss2.7 - view of a detailed information page

This page continues the exploration of the Design inSite database. By selecting "materials" from the front webpage, the user is taken to ss2.11. This page lists the types of materials included in the database categorized by basic headings. By selecting "smart materials" the user is taken to ss2.12 which gives a description of what smart materials are, and list more specific smart materials. By selecting "polymer gels" the user is taken to ss2.13. The "polymer gel" page describes what a gel is, what it does, how it is made, and some of its applications. The page has links to similar products, other websites that contain more specific information as well as producers of polymer gels.

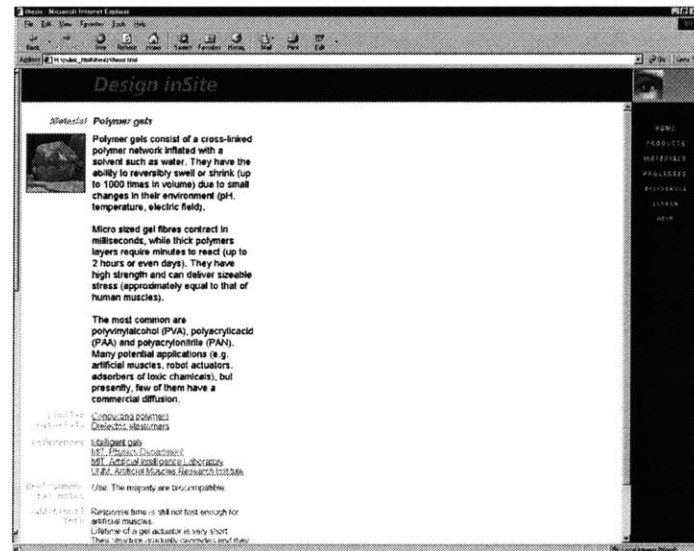
This material database is one of the more interesting examples studied because it is not a completely linear navigation but allows designers to browse through a very rich amount of information in an intuitive fashion. By creating links between materials, processes, and products designers can see the relationships that can come from an understanding of all three categories.



ss2.11 - view of the materials category search page



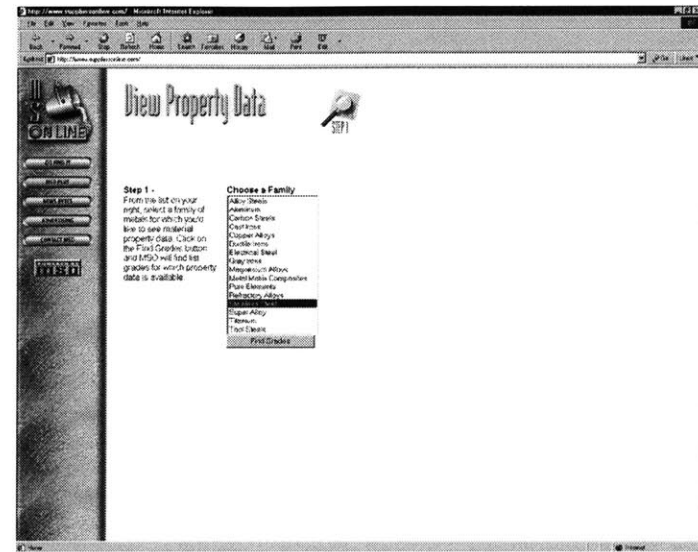
ss2.12 - list of returned products



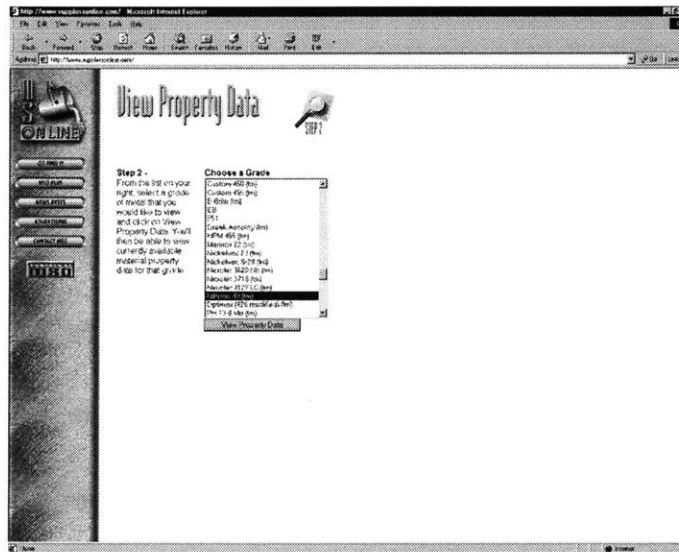
ss2.13 - view of a detailed information page

audience: engineers

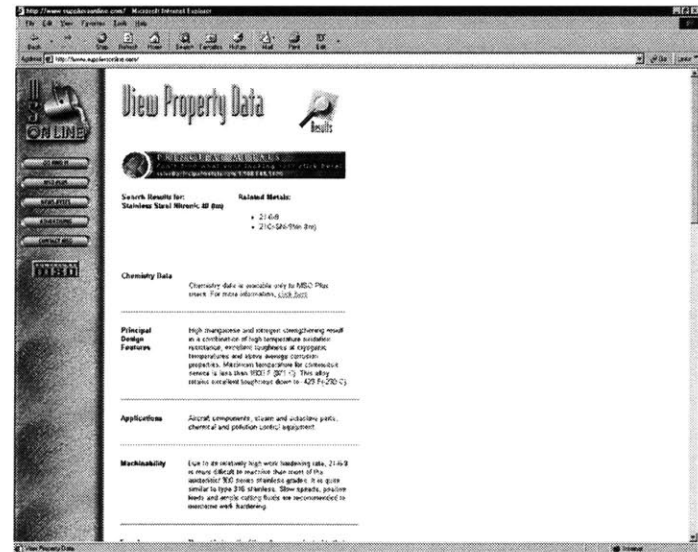
This is an example of a web database available to designers which has very detailed information on material properties and behavior. The first page has a listing of basic types of metals, in this case, selecting "stainless steel" takes the user to ss2.14. This page has very specific grades of stainless steel. Selecting "Nitronic 40" leads the user to the ss2.16. This page shows specifics of the material such as: machinability, forming, welding, heat treatment, hot working, cold working, physical data, and mechanical data. Although this example has very specific data as well as a clear interface, there is no ability to compare one material to another or browse horizontally within the database. The user must go back to the top level and select a different material. There is also no way to select the materials based on their properties, selection is only by the names. Architects are rarely familiar with this technical level of material details.



ss2.14 - view of the initial search page

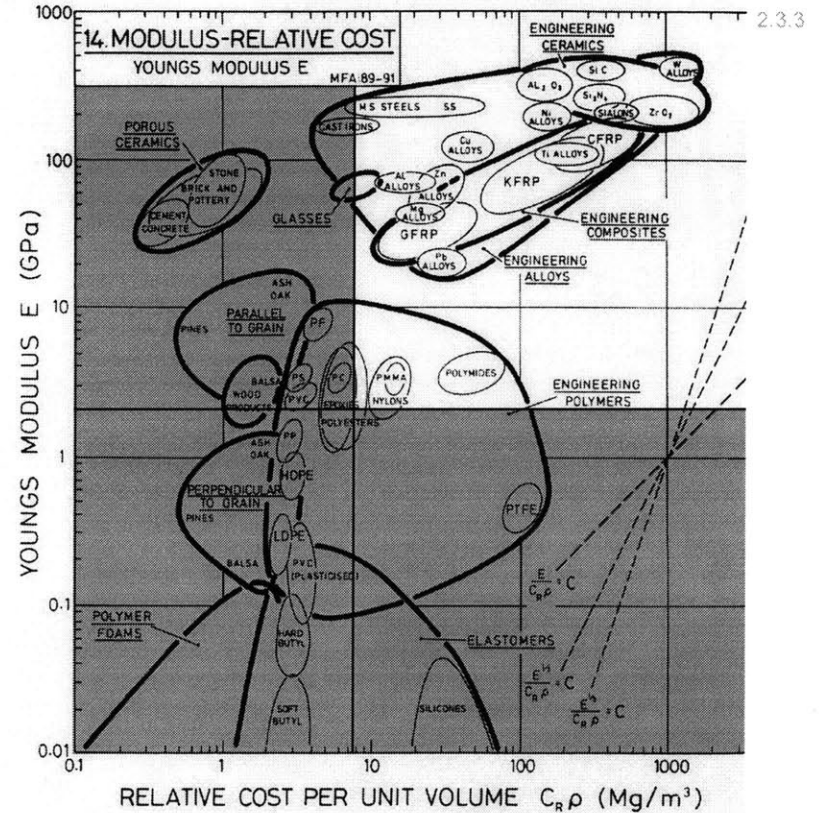


ss2.15 - view of a secondary page with groups of materials that fall under the most general category



Ashby defines design as being composed of two aspects: primary constraints which are imposed by external factors to the problem and the ability to maximize performance. The first aspect is seen as nonnegotiable because these are the factors that define the design problem. Examples of the first aspect could be the environment in which a design must be placed or the budget for the project. However the designer has complete control over the second aspect of design through decisions about how best to solve the design problem. There is rarely only one solution to maximizing performance. The charts (fig. 2.3.3) are created to aid a designer in the optimization process related to material selection by plotting lines at values specified by the designer on both axes. These lines begin cutting off options, in essence narrowing the acceptable field of materials. The opportunity exists to plot multiple constraints to minimize the number of materials. This reduced list of materials is seen as an initial subset of materials that a designer may begin implementing for a design.

While the Ashby charts present "all" materials within a single chart, all the performance aspects of the material cannot be presented in a single chart. In order for a designer to grasp a comprehensive understanding of a material, they would need to look at a number of the Ashby charts. The method is a truly comparative one in that materials are studied against one another on each chart, but the method is restricted to the chart's two properties. The task of comparing two materials on a more comprehensive scale would be an extremely difficult task, but it is a task that needs to be undertaken for architectural projects. The charts do aid a designer in the very early stages of the design process by helping to make the initial selection of options, unfortunately this graphic method becomes difficult to implement throughout the entire design process.



Ashby chart with lines designating designer's specifications 2.3.3 (diagram from *Material Selection in Mechanical Design* p.50)

2.4

the diagram

Now that the various types of material resources for architects have been explored and it has been shown that material data is plentiful but not completely usable, a strategy for selecting and comparing materials both comprehensively and visually will be presented as a response to the conditions and needs in the construction industry. This research evolved from work initially begun with the Ove Arup Research and Development (ARD) Materials Group in the summer of 1998. The open ended task at the time was to brainstorm ways that smart materials would be more readily introduced and subsequently accepted into the culture of the construction industry. From daily meetings with the smart materials expert Tony Sheehan, three objectives became more and more evident :

Select materials according to multiple performance parameters

This is necessary due to all the restrictions placed on a material by the various parties involved in the construction process.

Illustrate how advantages outweigh the economics

The benefits of a material need to be obvious since the main reason that they are not currently used is based on cost.

Visualize the dynamic behavior of materials

Data needs to become more understandable to designers through an emphasis on visual communication.

The goal of creating a material selection strategy for architects and designers was to extend the concept of performance based design into the realm of materials. Performance based design is the idea that design decisions are based on the overall performance of a building or system. The designer uses this criteria or performance goal as a reference point in the optimization process, fine tuning the design to achieve the desired results. In applying this concept to materials, the material's property behavior becomes the criteria with which to judge its performance.

The first step in the research was the investigation of the properties that a designer would be interested in when making a design decision [see list to the right]. A realization was quickly made that drivers in the material selection process depend on who will be making the decision, after all the act of building is a multidisciplinary endeavor. Designers are important but they are not the only people involved in the

economics initial cost life cycle cost expected life	conductive energy transmission convective energy transmission
appearance weathering chemical resistance color range texture porosity	acoustic sound transmission
architectural geometry user requirements cultural dimension	environmental embodied energy recyclable renewable
optical reflectance transparency direct light transmission diffused light transmission ultraviolet light transmission visible light transmission infrared light transmission	structure density weight strength ductility stiffness creep deformation prediction shrinkage moisture movement thermal expansion
fire behavior flame spread smoke generation structural collapse flamability	construction constructability confidence in use codes of practice past experience 3rd party certification safety health
thermal U-value solar heat transmission radiant energy transmission thermal time lag	uncertainty of performance cost/time of development liability availability innovation exposure to public

2.4.1

list of material properties that are of concern to designers



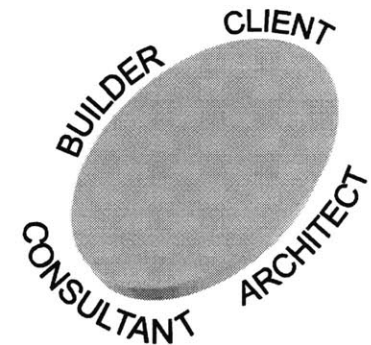
creation of a built project. Clients, builders, designers, and consultants all play critical roles in the decision making process. Thus, the problem became more complex, how to compare different materials using multiple parameters, based on different and often conflicting criteria? The image of a conference table kept resurfacing, members of a project team gathered around collectively making decisions.

The analogy of the conference table (fig. 2.4.2) was transformed into an organizing concept for the understanding of the material selection strategy. The placement around a table was used as a method for organizing the diverse properties that had been collected as exerting an influence on material selection. The roles within the design / construction process - client, architect, consultant, and builder - translated into four material property lobes which organized parameters according to economics, appearance, performance, and constructibility.

The simple organization for the graphic representation of material data was then tested through a number of scenarios and iterations. The first test of the material selection strategy was used for a lecture at the "Smart Materials and Adaptive Technologies Conference" at the Architectural Association in December 1998. The chart was used to compare traditional and new materials for glazing, structure and facades. The research received positive feedback from many of the practitioners and theoreticians currently working in the realm of materials.

It could almost be called the conspiracy of the detail, or the material, with its unequivocal, yet never openly expressed status. Despite their incredible importance, it seems impossible to discuss these aspects of architecture openly; they represent those shameful 'facts of life' that get swept under the carpet.

-Caroline Bos from Van Berkel & Bos Architecture

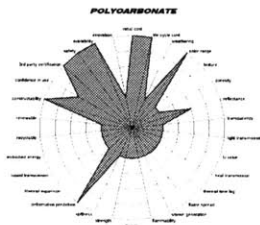
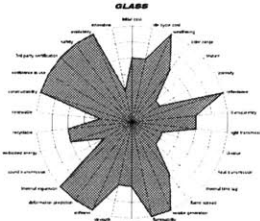
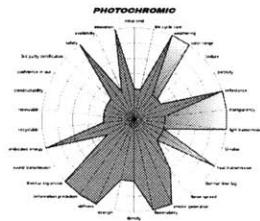


conference table diagram as the organizational basis for the diagram

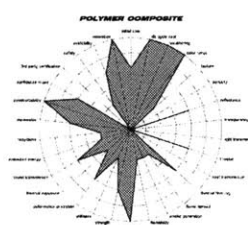
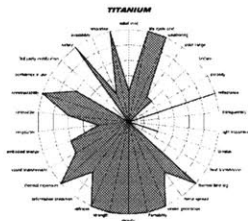
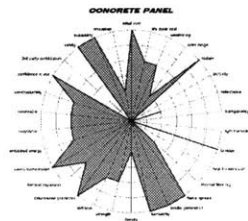
NEW MATERIALS

a visual design process

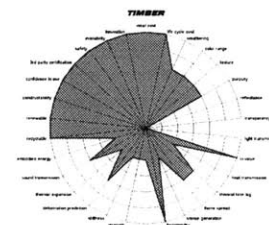
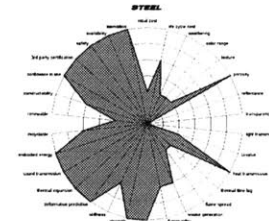
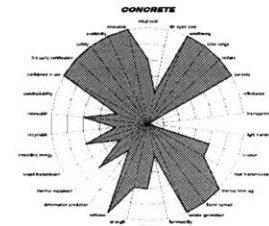
w
i
n
d
o
w
s



f
a
c
a
d
e
s



s
t
r
u
c
t
u
r
e



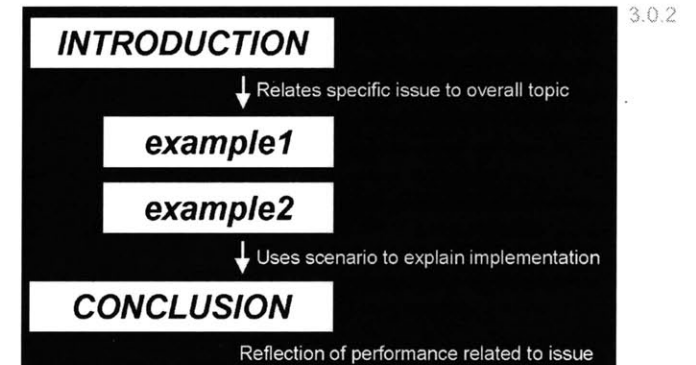
a joint project by: **ARUP R+D & MIT**

Tony Sheehan, Ove Arup & Partners R+D, LONDON
Karl Daubmann, Massachusetts Institute of Technology, House_n

3.0 *test cases*

This chapter presents a number of visual representation strategies. They have been developed to test the concepts of the thesis in response to the abundance of problems experienced in the presentation of information to designers during the material selection process. The strategies are presented as individual case studies. Each major heading has one or more examples of a material selection diagram in use. These studies were developed through a series of iterations that resolved the particular issues that were critical at a specific point in the material selection process. The overall research is complex and multilayered (fig. 3.0.1). The case studies are devised to present this complexity in the most understandable and clear manner.

Each case study follows a similar structure (fig. 3.0.2). Each begins with an introduction that has been developed as a response to the general issues presented in the beginning of the visualization strategy. This introduction is followed by an example that employed this material selection process. The case studies are illustrated by examples that discuss the concept behind the strategy, the process of the development, and the logistics of the data operations. A conclusion is included for the discussion of points related specifically to the issues raised. Each case study also contains a section that discusses future work that could be undertaken to build upon this research.



structure developed for the individual case studies

3.1 *data aquisition*

As a starting point in this discussion about the visual navigation of a materials database, it is necessary to track the evolution of thoughts regarding the data matrix. The development of the ideas presented in this chapter are related to the acquisition of data and the resultant organization of that data. These factors greatly influence the ability to navigate and visualize material properties and behavior.

Data Acquisition

Before it was possible to explore the material selection process, it was necessary to create a small but comprehensive database. The creation of this database was understood also as an opportunity to also investigate the methods with which architects gain material knowledge. The first assumption of the actual process of data acquisition was that one week should be an acceptable amount of time to build up a small, but comprehensive database related to glass. This one week block of time was to simulate a similar task that one might be assigned in an office environment. Glass was selected as a material to focus the research because of its level of complexity and many new innovations in the industry. Products had been identified for this work; types of glass, coatings, fillings, and films. All of the products would have to be represented by a comprehensive range of physical properties and behavior specifications. Three months after the project began the database was only 40% complete with no hope of it ever becoming a full matrix in the foreseeable future. The gaps in the data resulted from the time required to interact with product representatives and search for or obtain comprehensive data from manufacturers. Data found on the web is typically very general and information from manufacturers is usually very product, not material, specific. 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. After this exercise in data acquisition it became clear that the material selection process was necessary, but that it needed to be robust enough to deal with incomplete information.

Further complication of data acquisition stemmed from the fragmentation and complexity of manufacturers and researchers (fig. 3.1.1). There is no one source that contains all the information a designer would want to have. From an interview with James Carpenter, a practitioner whose work constantly attempts to push the boundaries of glass technology, the creation of a comprehensive glass database would be an enormous endeavor. There exists a number of both governmental and aca-

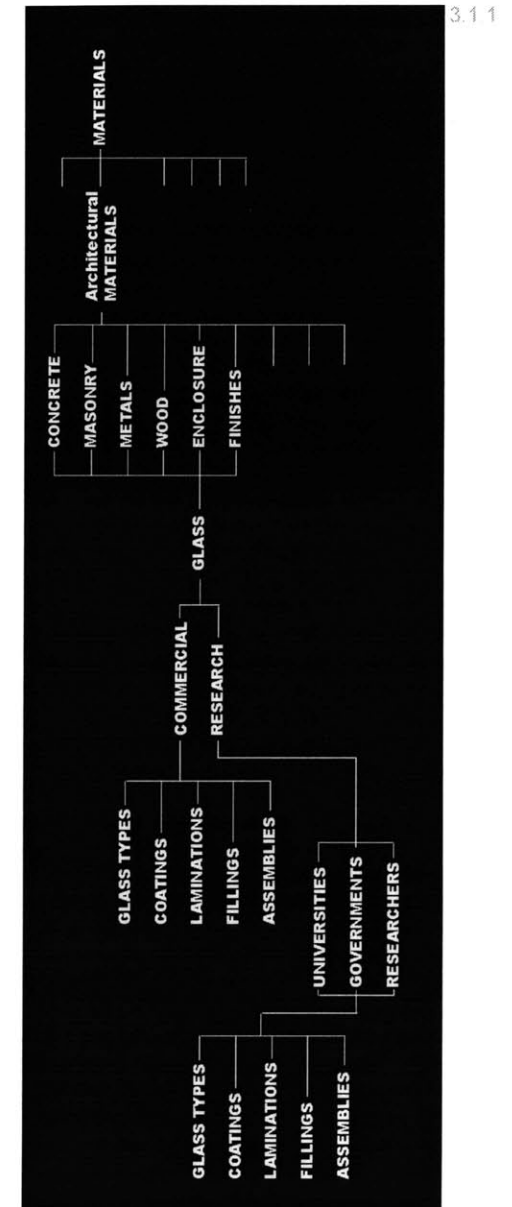



diagram illustrating complexity of centers for material knowledge



demographic institutions around the world that focus on only very specific aspects of glass. One institute will be the center for films, while another will focus on coatings. The information is then typically disseminated with papers or conference proceedings, the data never finding its way into a database, let alone a singular comprehensive database. Although data related to materials is growing daily, it is not accessible to designers in an easy to find or easy to compare format. This knowledge pointed to yet another reason that such a material selection system would be a needed addition to the tools of designers.

Variations in Standards

One of the most interesting aspects of this research was that it uncovered unforeseen variations in the types of standards for material property data. Discrepancies were discovered that related to units, types of testing, the results of these tests, as well as the ways the information was presented. According to Kaufman from a conference related to Materials Property Data, "Fundamental to the ability to network a variety of material property data sources is standardization of nomenclature, property names, definitions, and units among database builders and users, and standardization in the way data are input for subsequent searching and presentation... Similarly, the use of uniform or at least compatible database management systems will greatly enhance the ability to link and interactively search many data sources."

The next page (fig. 3.1.2) contains information available from the websites of Pilkington and Pittsburgh Plate Glass, two of the major glass producers for the construction industry. In comparing the two, it is instantly clear that they do not conform to any standard, either in terms of layout or the types of information that are included. Pilkington presents mostly optically related data, while PPG's information is more broad with issues of mechanical properties, optical properties, and thermal properties. Designers trying to compare the two products must first translate the information in an attempt to understand what values are compatible, then go about a comparison. One possible solution to this problem of incompatible information is the creation of data standards that codify how the information is to be presented. From the Materials Property Data conference, Northrup presented the need for "metadata" - data about data, "which would be a formal schema of data elements, together with associated controls on nomenclature, terms, measurement units". The metadata for the MIST project which served as a prototype for materials databases, formalized data entries and their relationships, linkages, individual data element

information from two different glass manufacturers, note lack of graphic and informational consistency

3.1.2

Pilkington data available from website

Monolithic Glass Performance Data		1/4" Monolithic Float Glass													
Product	Nominal Glass Thickness		Visible Light		Total Solar Energy		UV	U-Value				European U-Value (K-Value)		Solar Heat Gain Coefficient	Shading Coefficient
			Transmittance %	Reflectance %	Transmittance %	Reflectance %	Transmittance %	Summer		Winter		Air	Argon		
	in	mm					Air	Argon	Air	Argon	Air	Argon			
Arctic Blue Eclipse (#1)	1/4	6	25	43	20	29	5	1.1		1.1		5.8		0.34	0.40
Arctic Blue Eclipse (#2)	1/4	6	25	19	20	11	5	1.1		1.1		5.8		0.40	0.46

Pittsburg Plate Glass (PPG) data available from website

MECHANICAL PROPERTIES

- HARDNESS
 - MOH'S SCALE(SCRATCH HARDNESS): DIAMOND, 10; SAPPHIRE, 9, ETC. APPROXIMATELY: 6
 - KNOOP HARDNESS NUMBER (INDENTATION HARDNESS): INDENTER LOAD 500 GRAMS: 470
- POISSON'S RATIO: 0.22
- DENSITY: 156 LB/CF or 2.5 G/CCM
- MODULUS OF ELASTICITY (YOUNG'S): 10,600,000 PSI or 73.1 GPa
- TENSILE STRENGTH (DETERMINED AS MODULUS OF RUPTURE, ULTIMATE) 6,000 LB/SQ IN. 41.4 MPA
- SPECIFIC GRAVITY AT 70°F (21°C): 2.5
- WEIGHT

PER SQUARE FOOT	PER SQUARE METER
3/32" = 1.16 LBS	2.5 MM = 5.66 KG
1/8" = 1.56 LBS	3.0 MM = 7.62 KG
5/32" = 1.98 LBS	4.0 MM = 9.67 KG
3/16" = 2.43 LBS	5.0 MM = 11.86 KG
1/4" = 2.89 LBS	6.0 MM = 14.11 KG
5/16" = 4.05 LBS	8.0 MM = 19.77 KG
3/8" = 4.90 LBS	10.0 MM = 23.92 KG
1/2" = 6.36 LBS	12.0 MM = 31.05 KG

OPTICAL PROPERTIES

- (NOTE: OPTICAL PROPERTIES PROVIDED FOR CONTROL THICKNESS OF .223 IN.)
- COLOR DEEPENS AS THICKNESS INCREASES
 - REFRACTIVE INDEX MEASURED AT SODIUM "D" LINE: 1.5184
 - CIE ILLUMINATE "C" DATA
 - CHROMATICITY COORDINATES: X = 0.308 Y = 0.31
 - LUMINOUS TRANSMITTANCE: 89%
 - DOMINANT WAVELENGTH: 500 NM
 - EXCITATION PURITY: 0.7%
 - RADIANT ENERGY TRANSMITTANCE (ULTRAVIOLET - WAVELENGTH IN NANOMETERS)

WAVELENGTH	% TRANSMITTANCE	WAVELENGTH	% TRANSMITTANCE
300	0.2	350	73.6
310	1.4	WIDTH=108>360	83.6
320	8.5	370	85.6
330	30.6	380	84.6
340	57.0	390	87.2

THERMAL PROPERTIES

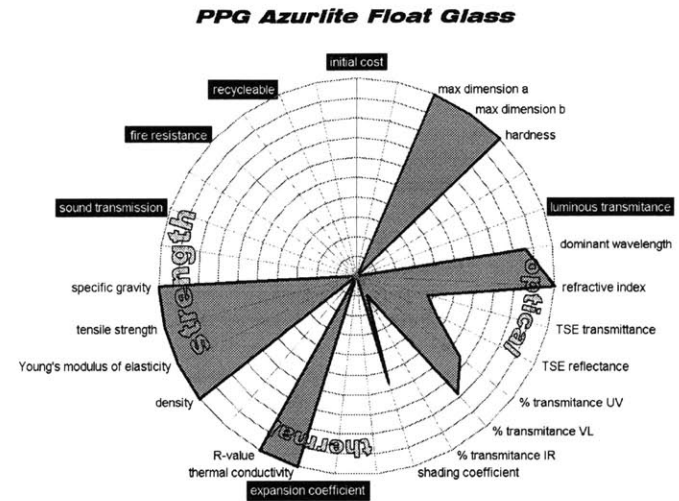
- HEMISPHERICAL EMISSIVITY AT 0-150°F (-18 TO 66°C): 0.84
- EXPANSION COEFFICIENT (LINEAR IN THE RANGE 25 TO 300 DEGREES CELSIUS)
 - PER DEGREE C: 8.6×10^{-6}
 - PER DEGREE F: 4.8×10^{-4}
- SPECIFIC HEAT (AT 32-212 DEGREES F / 0-100 DEGREES C): 0.205
- THERMAL CONDUCTIVITY (K) AT 120°F (49°C) MEASURED FOR A THICKNESS OF
 - ONE INCH BTU PER HOUR PER SQUARE FOOT PER DEGREE F: 6.5
 - WATT PER SQUARE METER PER DEGREE K (KELVIN): 36.9
- SOFTENING POINT: 1333°F or 723°C
- ANNEALING POINT: 1011°F or 544°C
- STRAIN POINT: 939°F or 504°C

characteristics, nomenclature, and units of measure and conversion. These five meta categories would make information from various sources comparable, allowing designers to make decisions without having to invest valuable time on data assessment.

Example 1 - Incomplete Data / Grey Data Impact on the Diagram

An important innovation related to the data matrix was the notion that the completed matrix of data is an unrealizable condition. Thus, a designer must be ready and able to work with an incomplete set of data. Since this is the present situation, it can only be improved upon. However, this reality also raises the issue of grey data - a term presented by Olsson from "Computer-Aided Materials Selection". 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.

The diagrams at the right demonstrate a couple of possible examples of how to flag grey data. The charts are from the detailed investigation of PPG glass types. The chart on the top highlights properties where data is not available. The designer then has the option to leave the data as it is, or fill in the gaps with values based on experience. The chart below 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.



highlighted properties that do not have values within the data matrix

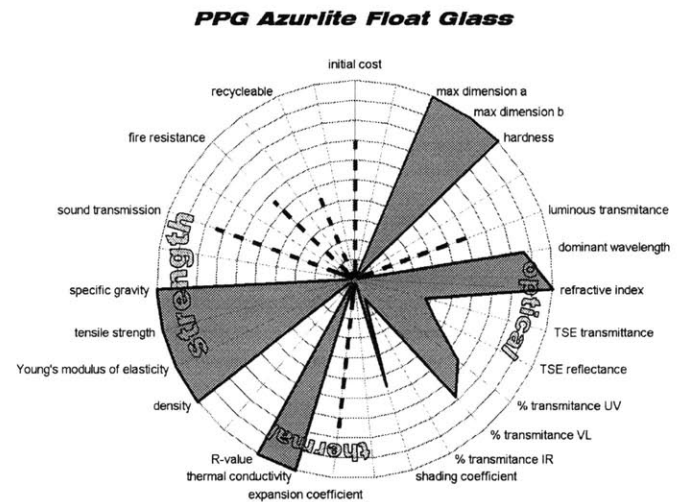


diagram with grey data values input as a "best guess" scenario, importance placed on representing the difference between the two types of values

Example 2 - Data Ranges

A common misunderstanding is that engineering is an exact science due to the importance placed on quantifying information. It was with this understanding that the material selection system was initiated with an emphasis placed on exact numbers for the database. It was then discovered to not be entirely necessary because values are typically doubled through the use of a safety factor. No designer wants to push a material to its ultimate limits; if the conditions change the material will be sure to fail. The emphasis then shifted to providing ranges of data, as opposed to exact numbers, that still allow designers to arrive at values.

Tony Sheehan from Arup R+D, indicates that an exact value is not necessary in many cases for construction. From his experience as a materials consultant within Arup R+D, builders often do not need to know the exact price for a material but would rather know the maximum price that it could be. If they are given an exact figure and the prices rise, problems will occur. If they are given a maximum price and the price ends up being cheaper, no one will complain when the construction comes in under budget. ***All of the parameters of materials work in a similar critical framework, a general range of values (as opposed to exact values) are sufficient to make decisions.***

The diagram to the right (fig. 3.1.5) is from the general glass analysis that compared major types of glass. Lead glass is a good example when discussing ranges of values because the production process and chemical composition can have dramatic effects on the performance of the glass resulting in a wide range of values for lead glass. Density for lead glass varies between 3.03 to 6.22 g/cm³.



property profile plotted for lead glass illustrating the ranges of values possible within the material family



Conclusions

The major focus of the research was considered to be the representation of data related to materials in construction. It did not take long to realize that problems with data acquisition, lack of standardization, and data organization have profound effects on how a database could be navigated and how the information could be represented. This area of the research has been explored by a number of research initiatives but they do not appear to have had an influence on the way information is presented by material suppliers. Presently, the responsibility and time taken to compare the various types of information falls within the realm of the designer. The goal is to liberate this needless comparison period, allowing the designer to deal with more important issues relating to design.

Future Work

The acquisition of data is a topic that needs to be investigated more specifically. One of the most interesting approaches that was discussed is that web agents (web software designed to retrieve specific information) could go out and locate specific data on the web and bring it back to the database. This type of method could also keep the database up to date, an important issue in an environment where new materials are created almost daily.

A second topic for future work related to building up the database is to have each material supplier create a web node with the specifications for their product. This type of organization creates a networked database, where information is not stored in one central location but is kept by various parties that are responsible for the information. The incentive with this organization is to force suppliers to supply information if they want designers to specify their products. In order to address the issue of mismatched information, the creator of the overall database needs to set standards. The suppliers can use the set up but maintain their own information - assuring that the information is kept up to date. This type of configuration also addresses the issue of legal responsibility by placing the burden of information accuracy upon the supplier.

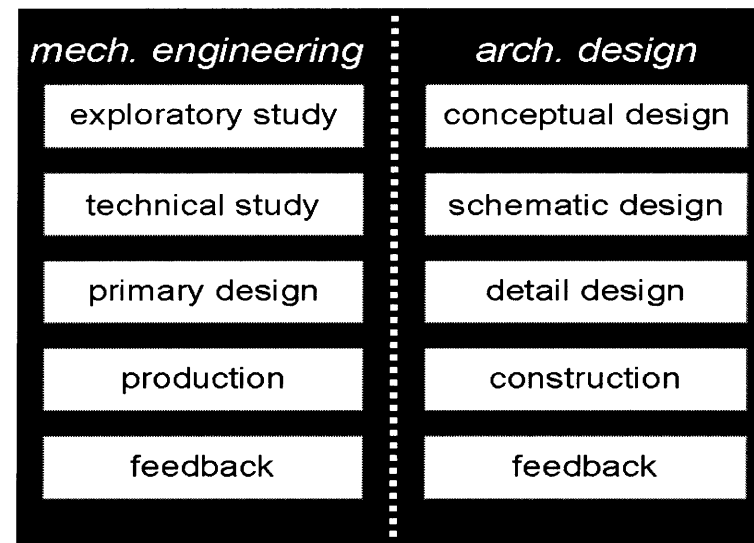
3.2 *process responsiveness*

Defining the Material Selection Process

Before it is possible to devise a process responsive material selection system, it is necessary to understand the process itself. The material selection process is not something that is commonly understood in the realm of architectural design. Most designers understand it as simply choosing a material. So, the first step in this process is to define what is meant by the phrase "material selection process". This is then followed by an exploration of the parameters which effect it. Once the process is clarified it must then be mapped back onto the architectural design process, grounding the material selection process within the commonly accepted context.

In the development of this definition for a material selection process in architecture it was necessary to explore other disciplines which have a clear understanding of the material selection process. Mechanical engineering proved to be the discipline most helpful in creating this definition because of the emphasis placed on the relationship between materials and production. Much research is done in an attempt to make sure the correct material is used for the correct application. Materials must be carefully selected since serious repercussions will be experienced if problems occur after production.

A commonly accepted model of the material selection process in mechanical engineering consists of five steps: exploratory study, technical study, primary design, production design, and feedback (fig. 3.2.1). Exploratory study is the period spent defining the problem and creating design objectives. For example, "materials for this application need to be very thin but also must have high insulating values". This very general definition of the design problem will lead to a broad range of possible materials. The technical study period is spent revising the designer's specifications and the design objectives. This revision leads to a narrowing of material families that may be applicable. Primary design places the material options in the possible design environments, investigating the entire life cycle of the product - from production to destruction. At this point in the process the material data must also be evaluated in terms of its relevance and especially its reliability. Production design explores the performance of one favorite material and a couple of alternatives in terms of production time, cost and dimensions. The feedback period builds on input from failure analysis and customer reaction based initially on a built prototype and finally on the produced product. [Olsson, 1980]



3.2.1

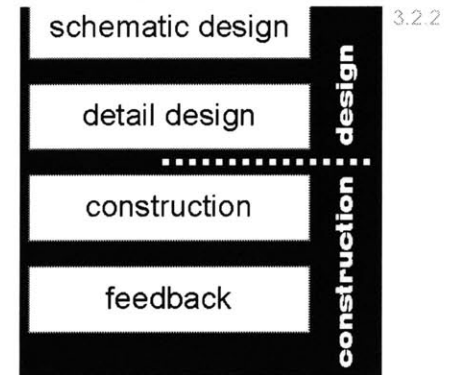
links created between mechanical engineering model of material selection and the architectural phases of the design process



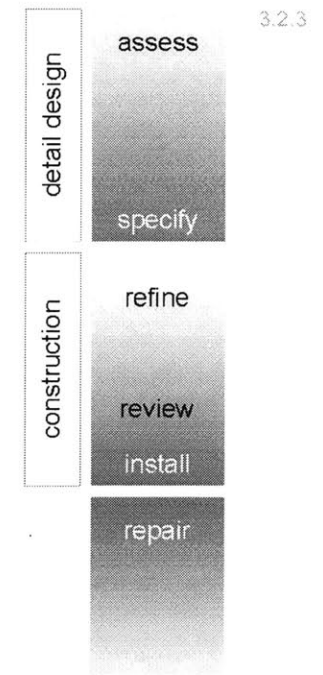
The practice of architecture does not place as much importance on materials as mechanical engineering, but the phases of architectural design are similar: conceptual design, schematic design, detail design, construction, and feedback. In architecture a break commonly occurs between design and construction, which accompanies the shift of responsibilities from the designer to the contractor.

Now that the framework has been set for the design / production process the material selection process can be explored in more detail (fig. 3.2.2). The design phase [conceptual, schematic and detail] is seen as the realm of the designer which ends with a set of documents being given to the constructor. The material selection process in this time frame is seen as an assessment of material options concluding with the specification of a material (fig. 3.2.3). At this point the builder refines the design and is able to propose alternates of "equal" quality. This creates a condition of further review of materials ending with the installation of the material. The last aspect related specifically to materials - repair - usually occurs when something goes wrong which provides 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 stages.

Two iterations can be identified in the architectural material selection process; design and construction. The design iteration begins by investigating all materials in general terms and concludes with the selection of one material after having studied multiple properties associated with it. This design selection is used as a benchmark for the builder. It allows for the proposal of appropriate alternates of equal quality. The second iteration occurs when the alternatives must be reviewed by the designer and client. In this second iteration the selection process compares a small number of materials in great detail, to insure that the alternate materials will perform as well as the original design material. Often compromises are made when one aspect may not be as good, but another parameter may be more suitable - for example, the material may not perform as well but is available sooner.



detail of discipline change from design [architect] to construction [builder]



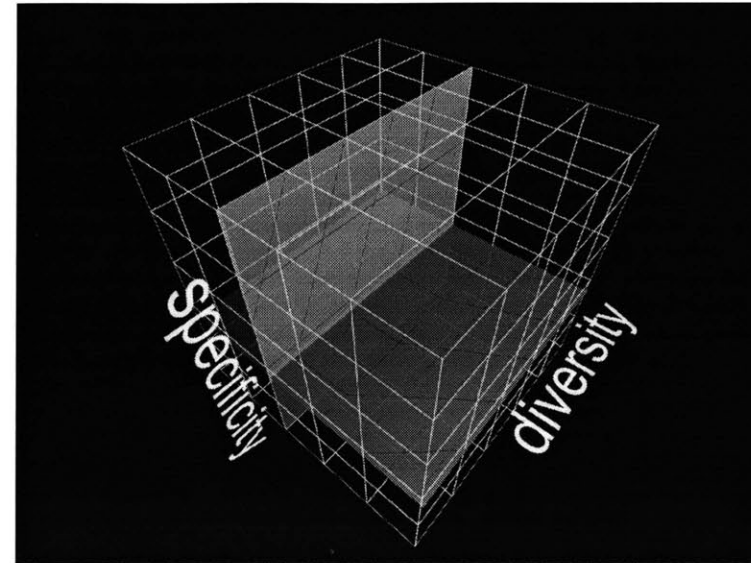
specifics of the material selection process mapped onto the phases of architectural design

Swimming in the Matrix

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. A three dimensional matrix is the best way to visualize the way both scenarios can be served.

One can conceive of the organization of the data matrix as a “swimming pool”. One can swim in a horizontal plane, exploring and comparing materials at similar levels of detail. By moving vertically the levels of detail either increase (by diving deeper) or simplify (by swimming to the surface). With these in mind the organization of the material data has two axes, diversity and specificity (fig. 3.2.4). The diversity of the database must exist so that it contains enough materials to compare. In addition to containing enough materials to choose from, there must also exist a high degree of specificity. Once a material is selected, detailed information about performance and behavior become critical to the design. A swimmer may want to begin the search in the center of the matrix and then move to a simpler level only if found necessary. This could occur if a designer wants to use the database to investigate alternatives proposed by a builder during the refine / review stage of the project.

The importance of organizing the data in this matrix format is that it allows for jumps in the specificity of the data. This aspect is necessary because without it, the database would need to contain all the data about a material, including data that may never be used. For example, light transmission of concrete would need to be included so that it could be compared with glass. But with the utilization of the matrix organization there is a level where glass and concrete can be compared - but on a general level. In moving to a more specific level, types of glass can be compared thus permitting the data to become more specific and relevant to glazing.



3.2.4

relationships created by the model of the data matrix as a method of organizing material information

Mapping onto the Process

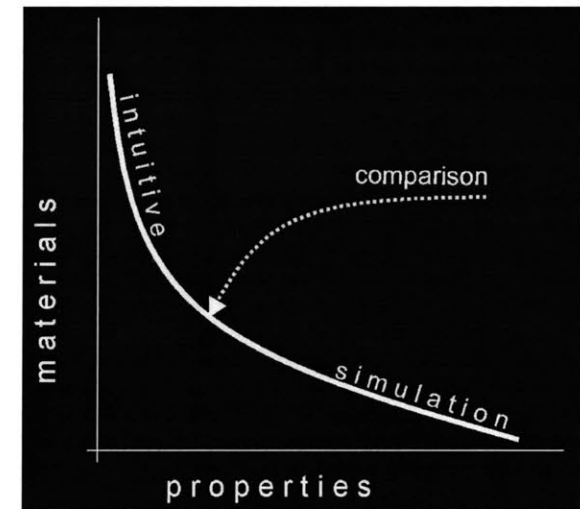
The mechanical engineering model of material selection can be illustrated quite clearly by plotting materials against properties (fig. 3.2.5). This shows the material selection process moving from a condition of many materials and minimal properties to a condition of few materials concerned with many properties. The architectural material selection process is a bit more complex (fig. 3.2.6). The curve is broken at the point when a contractor can propose alternates for construction. There is a redundancy built into this scenario where the designer must select a material and then may have to also study alternate options for that part of the project.

It is important to locate this investigation on the material / property curve to understand the relationships that are influential in the material selection process. This research begins at the central point on the curve because this is where a comparative strategy is the most appropriate (fig. 3.2.7). The top end of the curve can be characterized as so intuitive and broad that it does not necessarily 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. Movement from this central starting point can be extended in either direction. To extend the chart's applicability upward, more materials and general data must be added to the matrix - in essence increasing the diversity. The data matrix must be increased in an outward direction. To make this research more applicable lower on the material / property curve the data must become more detailed, adding depth to the data matrix.



3.2.5
3.2.6

comparison of mechanical engineering model of material selection process [left] and architectural model [right]



3.2.7

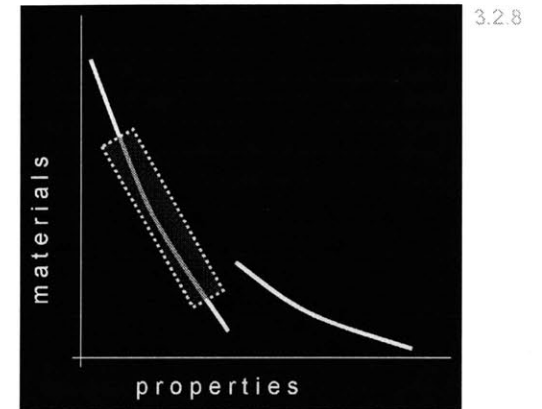
point of origin on curve with activities at extremes

Example 1 - Selection Navigation

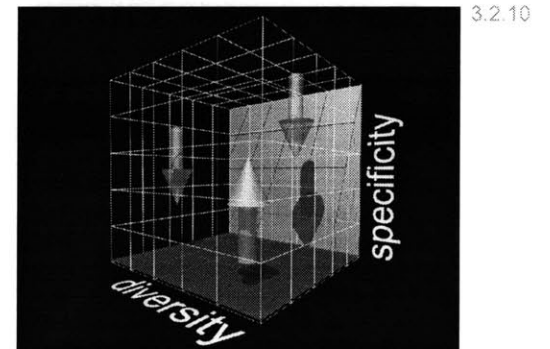
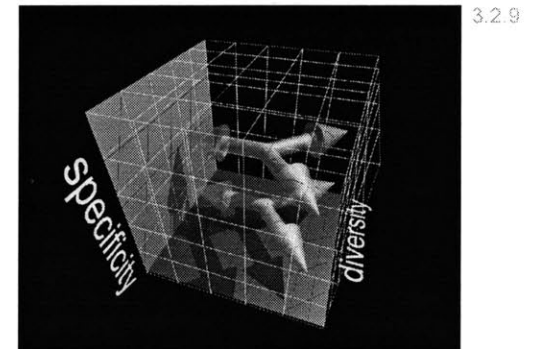
This example illustrates the ability of the visualization strategy to respond to the varying complexity of data associated with the material selection process. The example represents the assessment / specification activity of the selection process (fig. 3.2.8). Based on the material / property curve, 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.

Using the matrix as a model to understand the navigation process, 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 matrix allows for a progression from horizontal movement (comparisons) to vertical movement (increase or decrease in detailed information).

The selection process presented here [see next page for diagrammatic explanation] begins with the selection of seven materials that represent a broad range of types [concrete, timber, steel, titanium, polymer composite, glass, and plastic]. The next step is to identify some preliminary properties that can be used for an initial assessment. 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. At this level in the selection process the properties become more specific to the materials displayed.



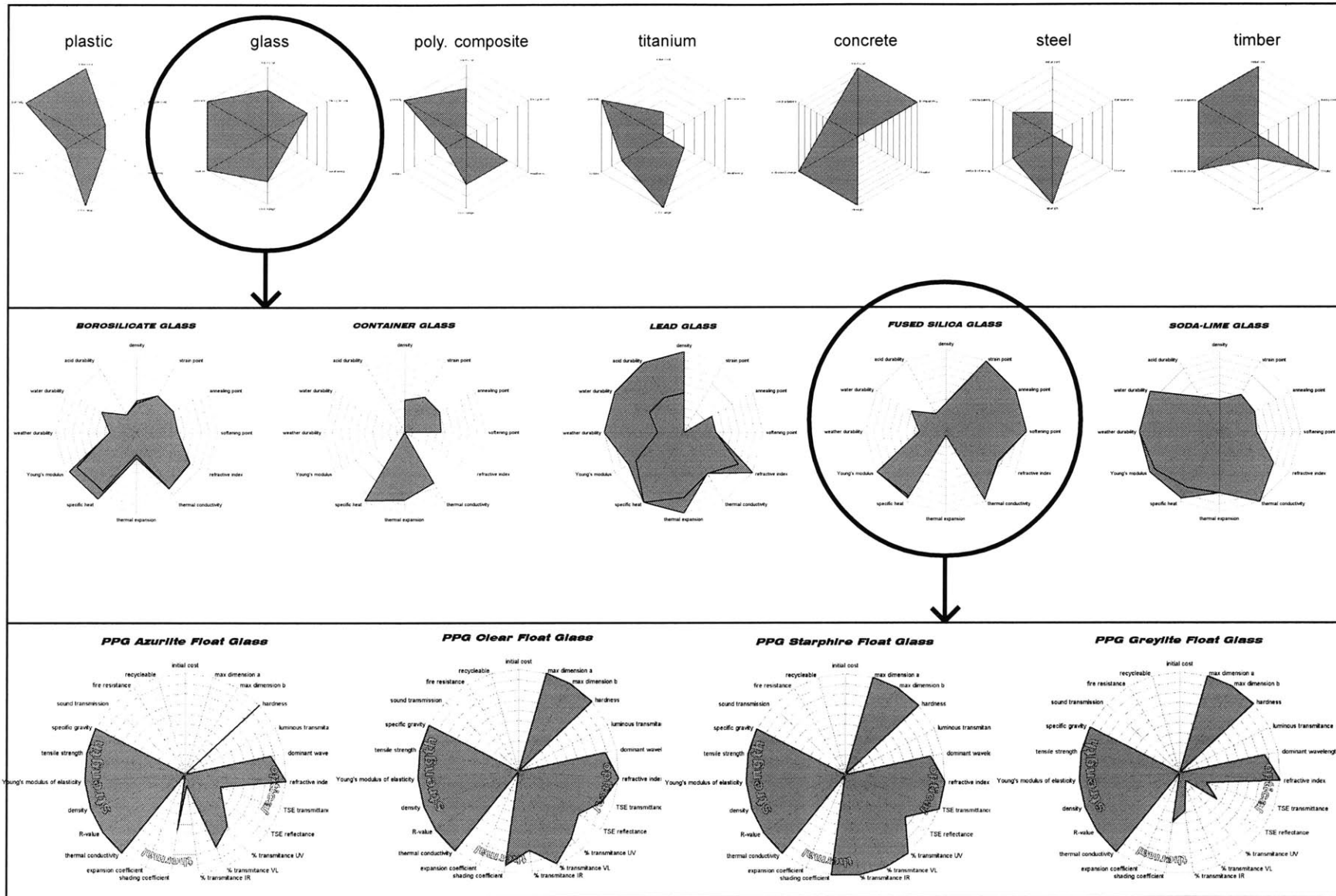
location of Example 1 on the material / property diagram



movement of navigation located within the matrix model of the data organization

map of material property charts illustrating levels of information relevant to different periods during the design process

3.2.11

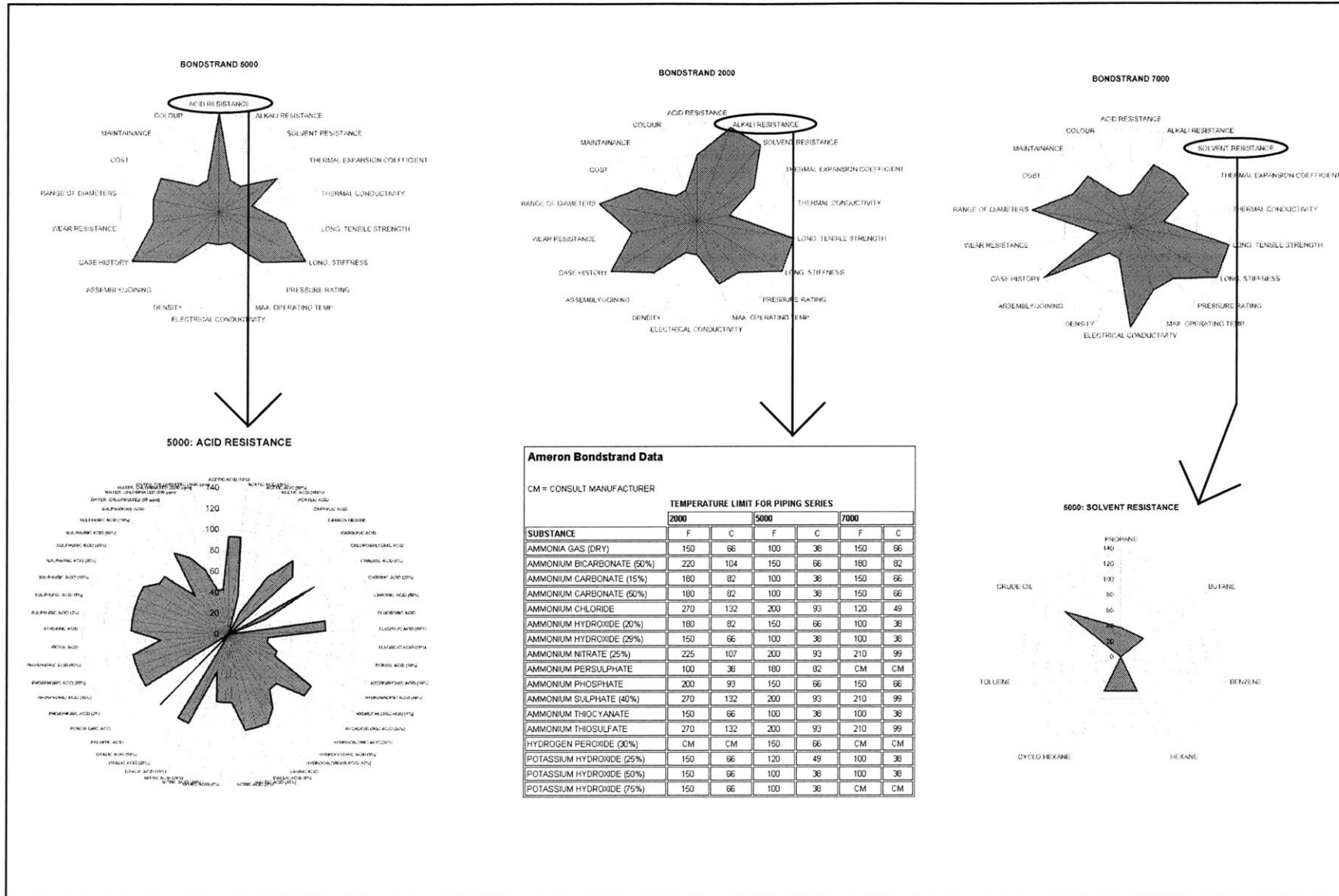




Example 2 - Hybrid Data Operations

This example represents a more specific use of the visualization used at the refine / review stage in the selection. It was prepared by Arup R+D for a client wanting to compare three types of pipes produced by the same manufacturer.

This example used multiple types of data operations (methods for data manipulation) to present the data. The first level of comparison was done using what has been called the “qualitative” method. This compares the information with a broad brush stroke and rates the properties with a simple technique that employs a scale that ranges from one to three (good, medium, or bad). This rating is done using general properties and information based on experience and the data supplied by the manufacturer. In this case one does not select the material but rather selects a property to move to a more specific level of information. This next level compared the three types of pipe based on parameters directly related to the property that had been selected. For instance, selecting “solvent resistance” displays the comparison based on: propane, crude oil, hexane, toluene, etc. In some instances a profile chart may not be the most appropriate means of representation. When “alkali resistance” is selected, a table presenting specific data for various chemicals is presented. Decisions must be made as to the most effective method for presenting information. Here, the table is employed because of the amount of information that must be presented. The benefit of using multiple charts is that specific information can be grouped on specific charts simplifying both the organization and navigation of the material data presentation.





Conclusion

The difficulty associated with the study of the design process is that it is different for every designer. The work that has been presented here uses the “typical” design process as a model for implementing a material selection strategy. The hope is that enough flexibility can be built into the system to allow it to respond fluidly to the idiosyncratic ways in which designers might work. See chapter 3.6 which investigates the ability of the system to respond to the designer.

The data matrix became a central discussion of many aspects of the diagramming strategy. How does one sort through thousands of materials, and how can they be compared comprehensively? Example One gives one possible way through which this problem can be addressed. At each point where one moves to increased detail the properties also shift to respond to the point in the design process. This eliminates the problem of having to include all types of data on all the materials in the database.

The hybrid approach to presenting the information illustrated in Example Two was an important innovation in dealing with the different types of data that need to be presented to designers. This example builds upon the understanding of the data matrix and the ability to move to deeper levels of detail and in so doing, operating on the data in different ways. At upper levels, the information is presented using a qualitative operation on the data. At deeper levels of information, a more quantitative approach is employed to present more specific types of data. At the most specific level of navigation, the designer is presented with tables of raw data. This type of information is most simply communicated in this fashion because of its complexity.

Future Work

The next step in the research related to this area is to have as many designers as possible use the system. In this way, many types of situations can be explored and the system can be modified and adapted to the needs of designers. This type of rigorous and practical application will clearly show where more flexibility is needed or where the system is not sufficiently user friendly.

3.3 *inclusive strategies*

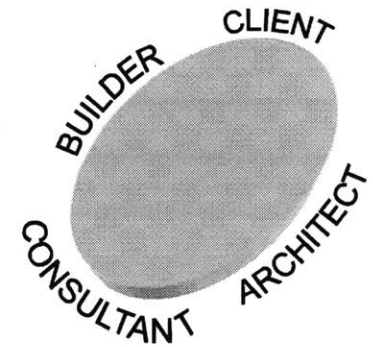
The material selection process must exploit the use of an integrated approach because of the diverse influences placed on materials by clients, builders, consultants, and designers each seeking sometimes different objectives. This integrated approach is further complicated by the diverse types of information that define the data matrix as well as the various types of output required by designers.

Multidisciplinary Aspects within Material Selection

For construction material selection, a strong emphasis must be placed on including a number of diverse material properties to create a comprehensive method for material selection. Keeping the range of terms broad allows for the selection method to be used by a wider range of disciplines involved in the design process and also allows for the method to be used for a wide range of materials.

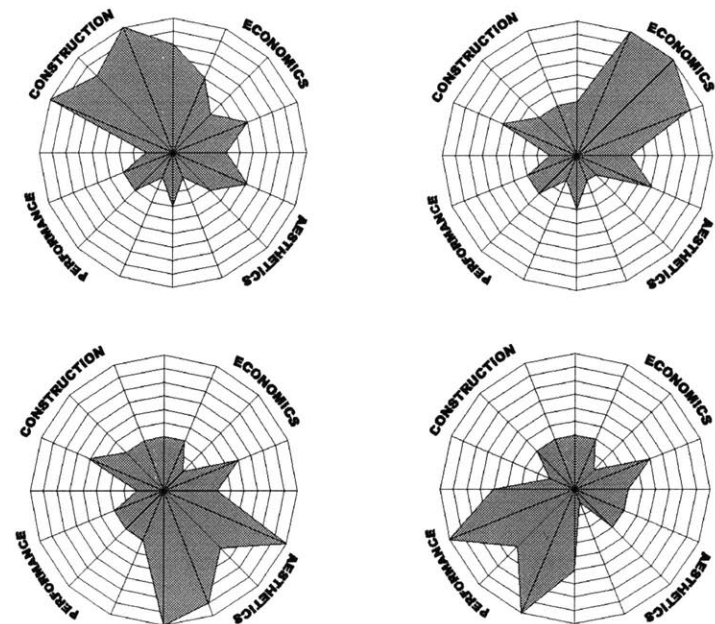
The selection method can become an important tool used by all the members of the project team when deciding on materials. General material properties can be used to develop an overall understanding of a material's performance. This general level of information allows for a broad understanding among the different disciplines involved with the project. The analogy adopted to create this comprehensive model is that of a conference table (fig. 3.3.1), around which all the project team members are gathered to resolve the important details of a design project - each member serving as an expert within the team. This analogy becomes not only an important model for the use of the tool but also for the development of the selection method itself. Based on this analogy, the discrete terms used for the model are shifted into locations around the chart, placing related discipline terms together. A possible example could be a chart composed of four areas related to the general heading of client, architect, consultant, and builder.

Having taken the necessary clues from the conference table analogy, the proposed visualization technique is further adapted to groupings of general qualities related to the material selection process (fig. 3.3.2). By locating the main headings around the graph, material property "*lobes*" develop, defined by the general headings of economics, appearance, performance, and constructibility. The groupings of the material properties into lobes allows for quick visual reference if the designer is familiar with the configuration - aiding in the understanding of the benefits attributed to different materials.



3.3.1

conference table arrangement as a basis for the organization of the diagram



3.3.2

simplified diagrams illustrate lobes of specialization

Incorporating Additional Information

In organizing the chart by disciplines, an open system is established that allows for many different consultants to work together in creating one comprehensive visualization. This open system permits the different members of the team to work together by plugging in the multiplicity of data into the discipline nodes that are created (fig. 3.3.3). This organization allows for the mobilization of data from discrete areas, and creates coherence since all of the data is included within the chart.

Information related to the material selection process can also come from a number of different types of sources. Because the material selection strategy makes use of a web based database it is possible to make links and incorporate various types of information from diverse sources.

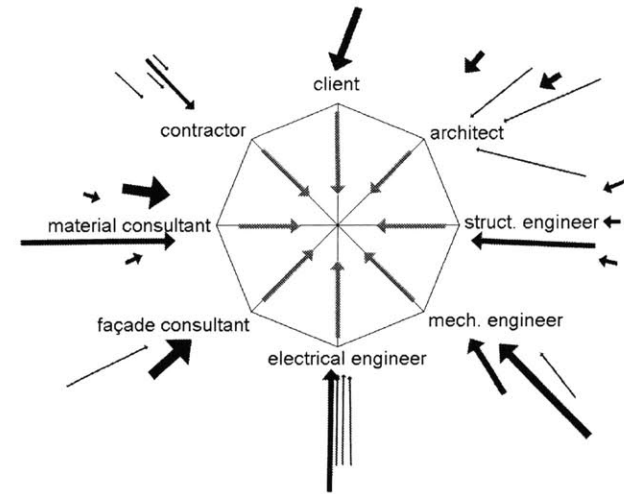
An important issue for any technical aspect is the validation of presented data. This inclusive strategy allowed for the linkages to sources of data. A user can dig deeper into the information to find out testing scenarios, who performed the testing, and other relevant information.

As discussed in Chapter 3.1 the data matrix was comprised of many varying types of values and units. By making the values of the material property diagrams interactive and “clickable” (fig. 3.3.4), users were able to access information about how to convert units, definitions for nonstandard nomenclature, or the equations from which values are derived. Links were also made to material producers and suppliers. These links allowed users to contact experts to ask questions related to specific applications. Similar to the examples of web based material databases from Chapter 2, links can also be made to photos of materials that can very clearly show available textures, colors, finishes, etc. The Sweet’s Online web database as discussed in Chapter 2 links to Excel spreadsheets and CAD details, so that users can download this information and add it to specifications or drawings. Case studies were also linked to materials or properties as a means of communicating problems that may have occurred with installations.

Extending the Usability

In addition to making links to external data and information sources, there were also opportunities to make links to tools that can be used to provide additional or more

3.3.3



the material property diagram becomes a “level playing field” for diverse types of information

3.3.4

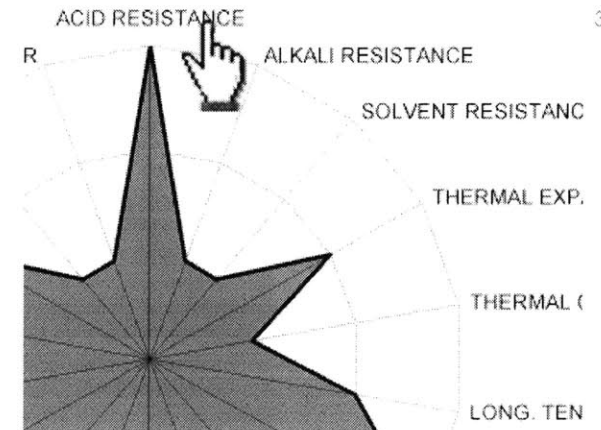



diagram illustrating ability to link to other forms of information



detailed information. The two most common of these possible links are simulation engines and algorithms. Algorithms could be used in cases where a database would not need to contain derived properties - properties that are dependent upon an external condition. Users would need to input the value with which to derive the property value. The simulation engines would be used where project specific information is available that is more detailed than the typical information available from a database. They could be used at more detailed levels of the design process where issues of complex conditions may exist, such as orientation. One such simulation would be a rendering program where lighting conditions could be tested with various materials for the designer to study both qualitative and quantitative issues and understand the impact on the overall architectural composition.

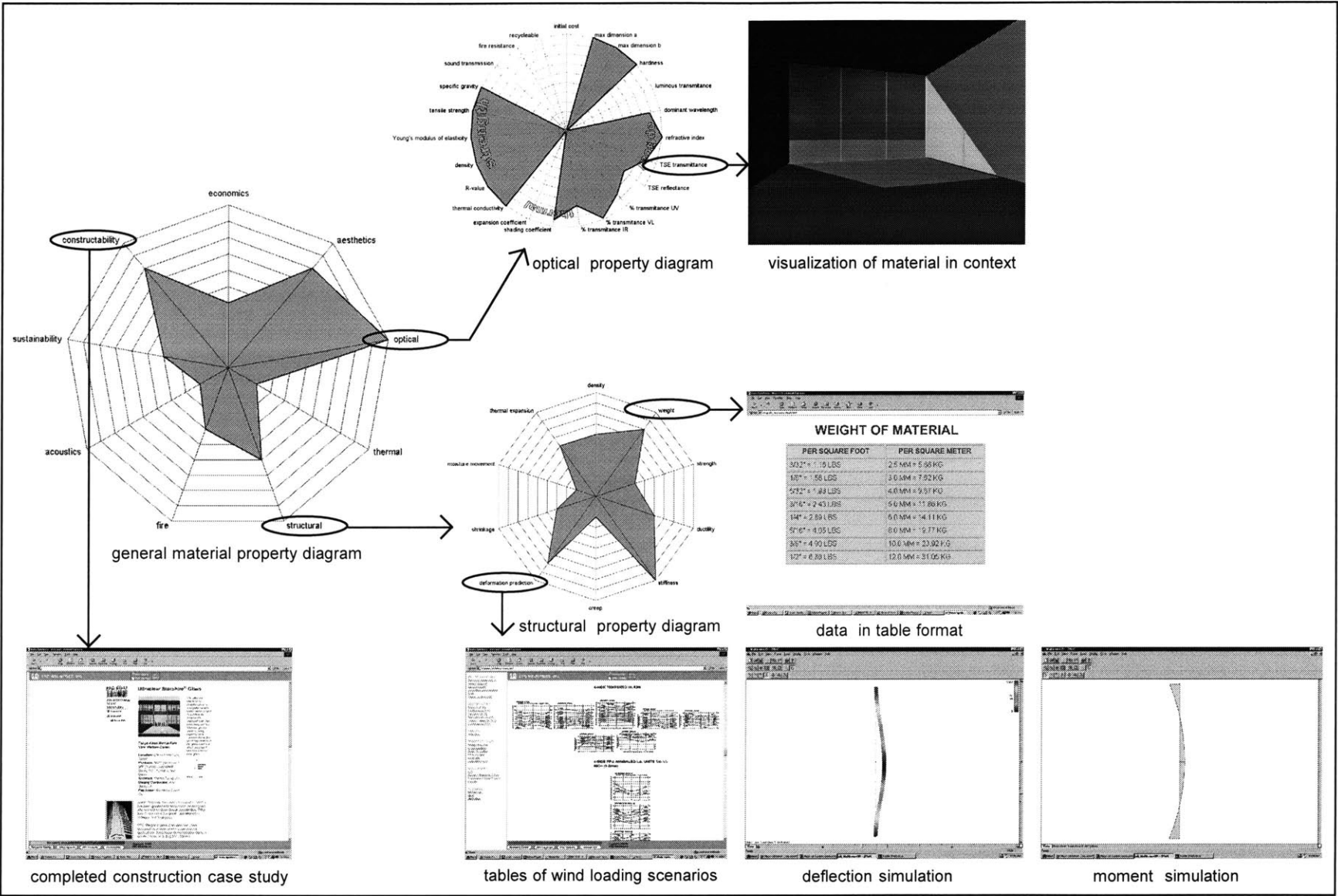
Example 1 - Expandability

This example of an expandable system illustrates the ability of the visualization strategy to incorporate multidisciplinary information and organize it in a clear and intuitive fashion. Similar to the example investigating process responsiveness, this example employs an interactive navigational strategy to organize the data.

This example (see fig. 3.3.5 on next page) explores the ability to incorporate diverse information related to clear float glass produced by PPG. The upper level [more general data] is presented in terms related to specific disciplines. The user can explore the rationale for the overall mapping of the material by selecting the specific disciplines - structural and optical presented on the next page. 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. Selecting "optical" presents the user with a similar looking chart, but this one is composed of properties specific to optical characteristics of glass. Selecting "transmittance" for the visible light spectrum brings the user to a simple simulation program where the material can be rendered in context. Clicking on "constructibility" presents the user with a case study of a project under construction. The "structural" discipline is also represented by another more detailed property plot, tables, and the ability to simulate the material under different loading conditions. The material selection graphic organizes and presents various types of information to the user in an intuitive manner that reflects the methods of the design process.

map of case study developed to explore linkages made between different types of data

3.3.5



Conclusion

One of the strongest benefits of the material selection strategy that has been presented is its ability to create a comprehensive display of material information. This comprehension comes from the scope of information that is included at different scales. With a broad range of topics, using a more qualitative data operation, many different disciplines can be included in one graphic representation of a material. This broad range gives a comprehensive snapshot of the material and its behavior. As more information is needed, the user can access the specifics about the qualitative decisions, and find the quantitative rationale for the qualitative representation. The ability to make links to producers, suppliers, tables, photos, additional graphics, and case studies give the user additional opportunities to get more detailed information from a variety of sources. The graphic interface acts as a central point with which to make all of the connections. In connection with a CAD package, such a material selection strategy could become more useful through the incorporation of added intelligence such as a simulation engine or calculators that can provide properties based on a condition supplied by the user. Again in this case the major benefit provided by the selection process is the ability to link many types of operations through one central interface, making the process more easy to track as well as to integrate into the designers repertoire.

Future Work

The aspect from this area of the research that could be further explored is the inclusion of this material selection interface into an object oriented CAD system. This would allow for objects to be embedded with material aspects that could be accessed during the design process. This incorporation of the material system allows for attributes of materials to be assigned to CAD objects. If a designer builds a CAD model with blocks that have defined material properties, when it comes time to render or analyze the model, the material information will already be present thus facilitating a smooth connection from one design operation to the next. This is critical to the overall success of such a material selection tool. Isolation from the rest of the design process would become too cumbersome for the use by designers.

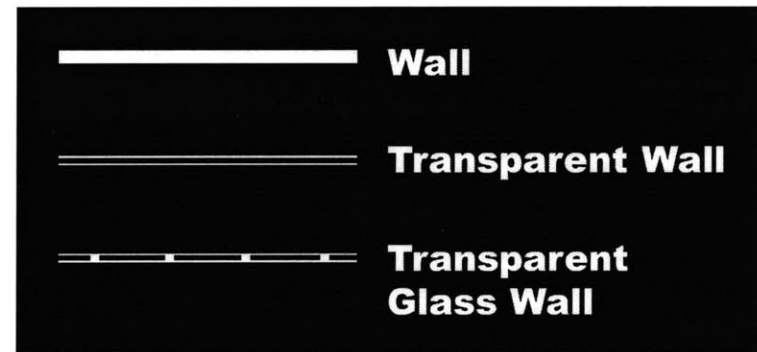


diagram illustrating the material attributes for the design of a simple wall

3.4

new materials

Many advancements in the field of materials have resulted from a convergence of innovations in biology, engineering, computers and technology, however these advancements have not found their way into the mainstream construction industry. The impetus for the material selection diagram is that new materials will not be accepted as conventional materials until designers are able to understand the implications and innovations these materials can offer. This material selection strategy educates designers on the benefits of these new materials through the visualization of the dynamic and varied qualities offered by these new materials.

High Performance / Smart Materials

Two types of new materials have moved into the spotlight in recent years: high performance materials and smart materials. According to Addington and Schodek, both types of materials are engineered for specific applications and attempt to optimize the material behaviors for particular environmental states. The critical difference between the two is that high performance materials are optimized for single and specific states, while smart materials are optimized for multiple states. A smart material can alter one or more of its properties in response to a change in the conditions where in the material is placed. The material changes can be related to transformations of chemical, mechanical, optical, electrical, magnetic and/or thermal conditions.

The development of these new materials not only brings about new opportunities for design but creates a need to critically rethink the way materials are understood. Traditionally, materials have been considered static elements of the building fabric, with the exception of deterioration over time. Now materials are able to take an active role in the building's response to its environment and its inhabitants. The most exciting quality offered by smart materials is their dynamic properties. Designers have always been interested in the possibility of dynamic and active qualities of buildings, but the actual application has focused only on the temporal scale (in years) - "Will the building last 10 years?". After all, buildings are not supposed to move or change. The analogy between the building skin and human skin can be used as an example that breaks from this static design vision. The facade of a building can be very solid and closed, with no connection between interior and exterior, or it can become a living layer that allows for the constant interchange of air, sun, and heat to pass between inside and outside. In order for designers to exploit materials in such a deliberate way they must be able to test design scenarios based on material properties and behaviors.

smart:

having or showing mental alertness and quickness of perception, shrewd informed calculation, or contrived resourcefulness, marked by or suggesting brisk vigor, speedy effective activity, or spirited-liveliness.

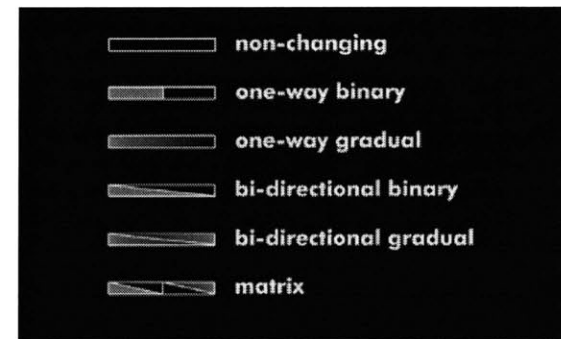
Webster's Third International Dictionary of the English Language

Prior to the development of smart materials, designers treated material changes as annoyances. Traditional changes in materials such as thermal expansion and deflection, were approached as negative transformations. Expansion joints or deeper structural members were measures taken to combat these dynamic aspects of buildings. Smart materials bring the element of time and change to the forefront, raising questions like, "What will the building look like in 10 minutes?" and, "How will the building transform in response to a change in temperature?". Designing with smart materials must be approached with a clockmaker's view of the world - create it and set it in motion. The ability to set the design in motion is facilitated by the visualization of the dynamic behavior of materials, permitting designers to test their design intentions.

Types of Changes

Smart materials transform material changes from liabilities to assets. Smart materials extend the traditional responses exhibited by materials both by type and range. Traditional changes include non-changing, one-way binary, and one-way gradual transformations. Stone, a stable material, could be classified as non-changing because it does not degrade in typical applications. An example of a one-way binary change could be a material failure; glass exemplifies this dramatic type of change. This change is clearly one-way since there is no way to reverse the transformation, and binary since once the glass deflects beyond a certain limit it undergoes the transformation from stable to broken. In contrast, weathering could be understood as a subtle one-way gradual change that tends to break down materials when exposed to external conditions - the process is not commonly reversible. Some materials are actually used specifically for the way they age and weather, copper is one example that patinas over time - transforming from a natural copper color to a light matte green finish. In some circles aluminum is considered a smart material because of the way the surface oxidizes when it is scratched. Many designers will select aluminum to exploit this oxidation (also a one-way gradual change) which creates a protective layer for the surface.

Smart materials offer designers a number of options that extend the range of material change. New possibilities for material transformations include bi-directional binary change, bi-directional gradual change, and matrix transformations. Switchable glazing illustrates a bi-directional binary change. Switchable glazing or privacy glass is able to change from transparent to milky white (translucent). The material's state



3.4.1

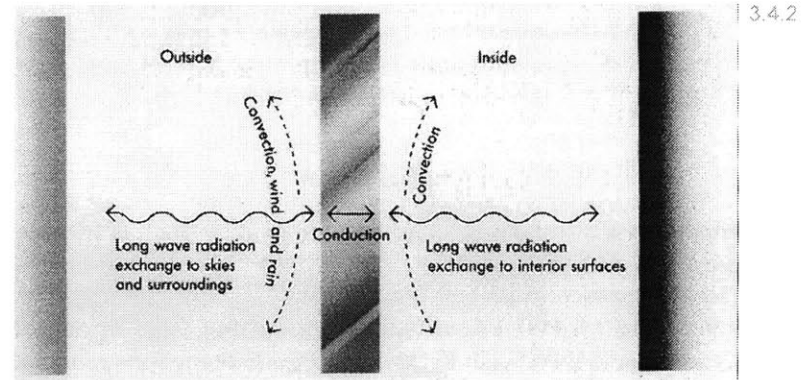
potential changes and transformations that occur in materials

at rest is translucent and when charged with a low voltage, the film (laminated between two sheets of glass) changes to clear. The change can move back and forth by turning the power on (for clear) and off (for privacy). An example that exhibits bi-directional gradual transformation is electro-chromic glazing. This glazing system can transform from clear to opaque and any stage in between by again applying a low voltage. In this case, the material does not need to be constantly stimulated to achieve a desired effect, once changed, the material maintains its level of transparency through a memory effect of the material. The final type of transformation is a matrix change. This would be a material that can alter more than two properties. At this point in time no materials are available that can offer this range of transformations, but through combinations of materials this effect can be achieved. Matrix transformations will most likely be a result of layered systems that will make use of multiple smart materials that are able to interact and communicate, creating smart components.

Example 1 - Mapping Material Transformations

As a method of testing the ability to plot the transformations of materials, an abbreviated investigation was carried out that focused on materials used for glazing units. The starting point was the criteria for the selection of glazing materials. It became clear that glass itself is not a material that works well thermally as part of a building envelope because it allows for the transfer of energy through conduction, convection, and radiation (see diagram). The problem with a single glazed window is that the thermal resistance (as a factor of conduction) is completely determined by the glass thickness. This leads to the need for multiple glazing, creating the opportunity to fill the interior gap with additional elements to suppress the transfer of energy. The material selection diagram was then employed as a tool for the comparison of various infill materials concentrated on thermal aspects of glazing units.

The first solution to mediate the thermal energy transfer was to fill the airspace with an inert gas. This gas filling reduces conduction through the gap. The depth of the airspace increases the thermal resistance up to 15cm, at which point convection occurs, reducing any gains for an increase in depth. An important issue that needs to be solved with filling the airspace with gas is the seal and spacer around the edge of the glazing unit. Should this seal fail, the window loses its thermal resistance. Key aspects of the gas filling technology that are expressed when plotting the material



thermal energy exchange related to glass
3.4.2(diagram from Glass in Building p.130)

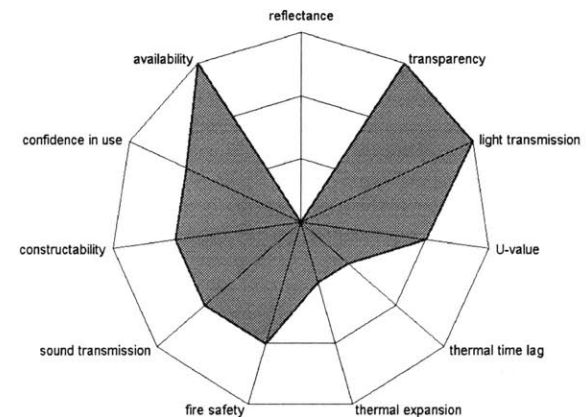
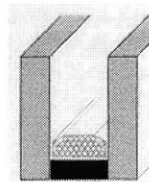


diagram of gas filled double pane window (note: low constructability, high transparency)
3.4.3(diagram from Glass in Architecture p.265)

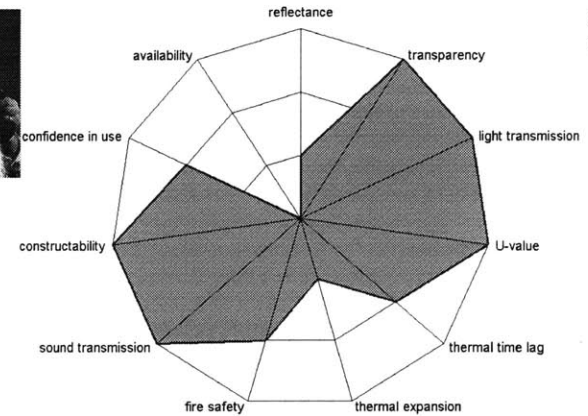


include the optical characteristics, constructibility, and availability. The optical character of the gas filling is not reflective, meaning that it allows for high transparency and high light transmission. In relationship to the other fillings studied, the gas filling has the negative aspects already discussed related to the constructibility of the seal, but this as also the most common technology studied so it rated high with availability.

Monolithic aerogels were the second infill material investigated. It is a new material that has not seen widespread application but should be commercially available in two to three years. According to NASA Space Science News, aerogels are the strongest and lightest (per weight) transparent building material. A one inch thick aerogel has the same insulation value as 15 panes of glass with air spaces. Current research is looking at using aerogels sandwiched between two sheets of glass, creating a high insulation window that would actually have a higher R-value than a solid wall. Aerogel is an extremely porous silicate structure that works well as a thermal and acoustic insulator. As illustrated in the chart, due to its high transparency, aerogels also allow light to pass through the window assembly. The other important aspect is that it can easily be placed within a glazing unit, eliminating the problems of the seal. Thermal resistance can be increased by evacuating the gap of air, and in this instance the aerogel acts as a spacer to resist the inward suction of the two panes of glass.

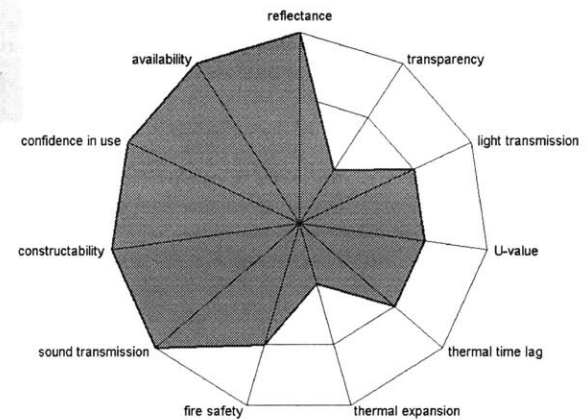
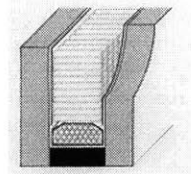
Translucent insulation was the third infill material studied. It is typically constructed of thin polycarbonate tubes that are oriented perpendicular to the glass panes. The capillaries allow for the transmission of low angle light through the airspace. The translucent insulation blocks out high level sunlight, which poses the greatest challenge because it causes overheating problems. The main advantages of this material are that it reduces convective flows within the airspace (increasing thermal resistance) and it has the ability to reflect incident sunlight, producing greater levels of diffused lighting deeper into a space. The diagram clearly shows that it is an easy material with which to work thus rating it high for constructability, confidence in use, and high availability.

Micro louvers can be classified as high performance materials because they are optimized to block out high angle sunlight while reflecting low level light. In summer, high angle light produces problems of overheating, while in winter, low level light occurs when solar radiation can be used for heating purposes within the building.



3.4.5
3.4.6

diagram of double pane window with monolithic aerogel infill
(note: high constructability, high U-value)
3.4.5 (photo from Lawrence Berkley Nation Labs, aerogel webpage)



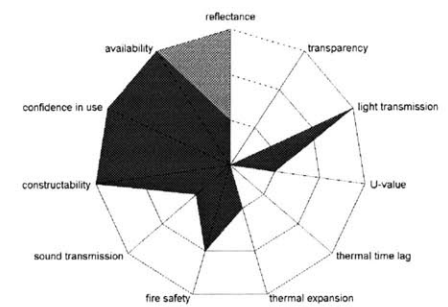
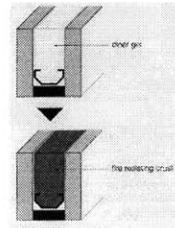
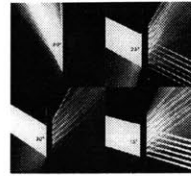
3.4.7
3.4.8

diagram of double pane window with translucent insulation infill
(note: high constructability, low transparency)
3.4.7(diagram from Glass in Architecture p.265)

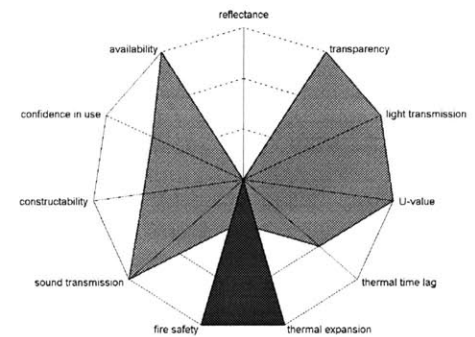
To account for this temporal aspect of the material, the chart has two components, high light and low light. The negative aspects, as seen on the chart, are that the louvers have no effect on thermal resistance and also block views through the windows. The aspects that transform from one condition to the next are reflectance and light transmission, depending on the angle of the sunlight.

Intumescent gel is a smart material that has only recently started production as a glazing unit infill material. This material has been used for many years for fireproofing purposes as a finish for exposed structural steel. Intumescent materials are applied like a paint and when the temperature of the substrate increases the material begins to foam, creating a thermally protective crust. In glazing, the material is used for the same purposes. Advancements with the technology now have created a transparent gel that can be sandwiched between two sheets of glass. These types of glazing units have fire ratings up to two hours. According to the manufacturer, the makeup of the gel also acts well as a thermal and acoustic insulator. The chart illustrates the two conditions of the intumescent gel glazing unit, one layer represents the normal condition, the second shows when the unit is exposed to fire. The two parameters that undergo a transformation are thermal expansion and fire safety.

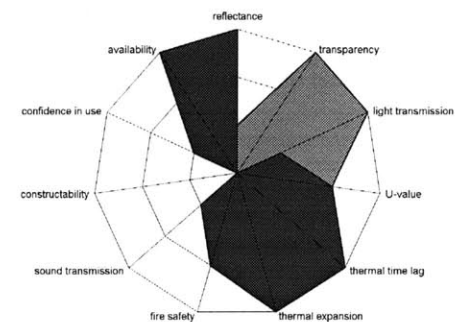
Phase change material (PCM) was the last technology explored for filling the airspace in glazing units. Work with placing this material within the airspace was carried out at the ETH in a PHD dissertation by Heinrich Manz. This research explored placing PCM within the cavity of glass blocks to create a thermal storage wall system. Phase change materials work by storing and releasing latent thermal energy through a phase change from liquid to solid. The PCM can be designed to change phases at a predetermined temperature. In this case, the material transforms from solid to liquid at room temperature, releasing stored energy. The diagram illustrates that this phase change has implications on reflectance, transparency, and light transmission (in its solid state it does not allow views or light through). The PCM is designed to create a thermal time lag because of its response to temperature. Easily made through the use of available salts diluted in a water mixture, the PCM becomes problematic as a building material because of its liquid phase. This makes the material extremely heavy, and makes the issue of the seal a major concern. One other aspect shown with the diagram is the thermal expansion of the material. In experiments at the ETH, the PCM actually broke the glass block samples, resulting in the very low rating for constructability.



3.4.9 diagram of double pane window with micro-louver filling (note: high constructability and the transformation of light transmission for high and low light) 3.4.9 (diagram from Intelligent Glass Facades p.73)



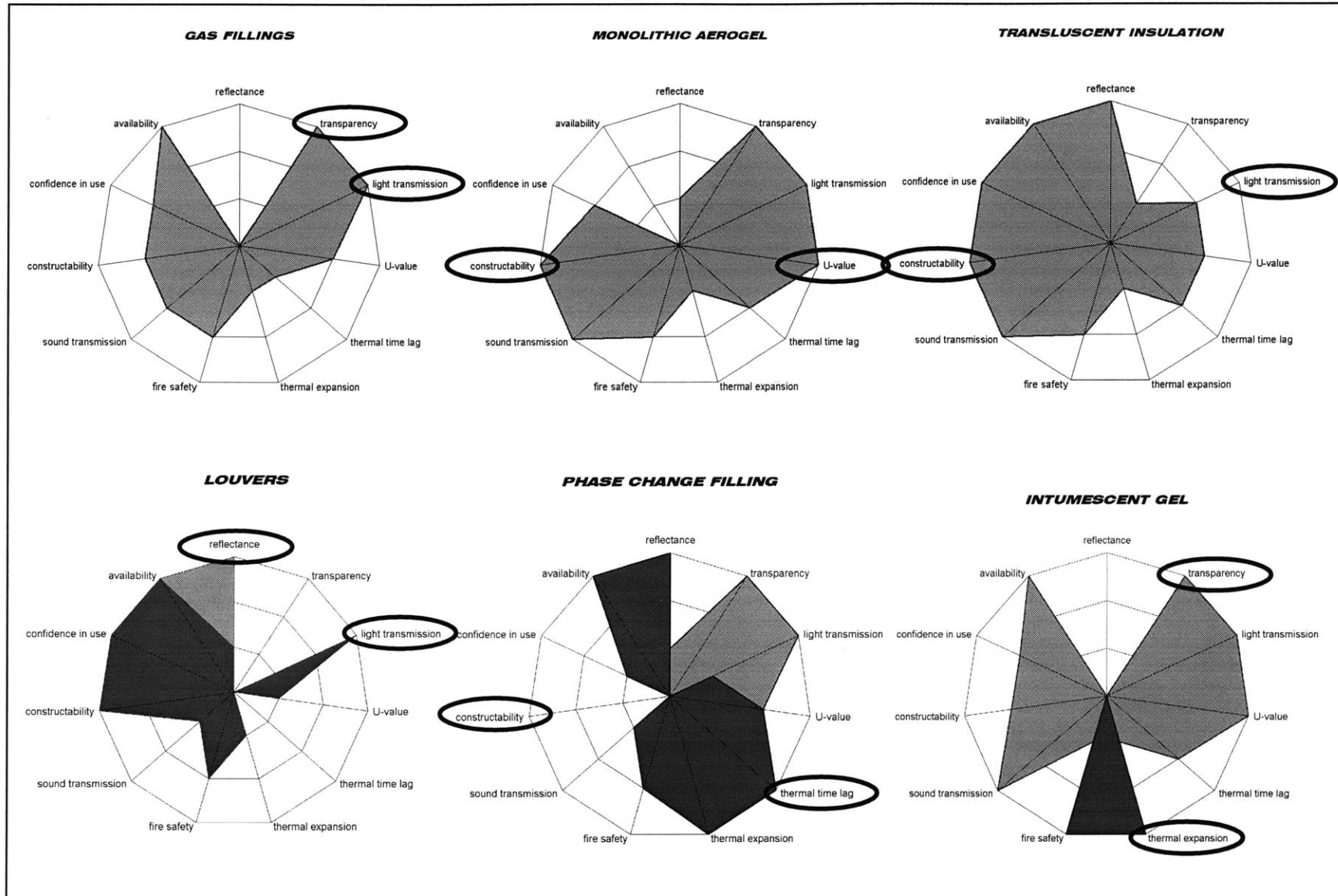
3.4.11 diagram of double pane window with intumescent gel filling (note: transformation of thermal expansion as used for fire safety) 3.4.11 (diagram from Glass in Architecture p.265)



3.4.12 diagram of double pane window filled with phase change material (note: very low constructability, and the transformation of thermal time lag)

comparison of glazing infill layers (the circles highlight aspects that may be a driver to the selection or rejection of the material for an application)

3.4.14





Conclusions

The field of new materials offers exciting possibilities for designers, allowing them to explore dynamic aspects of materials that can respond to the changing environment in which they are placed. The visual material selection process was an attempt to graphically represent the dynamic behavior of the new materials. The material diagrams are successful as they clearly illustrate the properties of the materials that transform, in addition they also show the range of transformation that a material may undergo. Unfortunately, this represents only the beginning of the work that needs to be completed before designers will be able to fully exploit smart materials. The studies were also useful because they uncovered additional issues that need to be addressed in a more focused exploration.

Future Work

An important future aspect for the material selection system is the mapping of materials over time. Conditions such as exposure to UV light and high humidity can cause materials to degrade and breakdown. By investigating this area in more detail, material databases can aid designers in selecting materials that will create more durable buildings.

As already stated, smart materials respond to their environments, creating another layer of complexity for the material selection process. This places importance on the ability to not only plot dynamic material properties but to also plot the external conditions that bring about a pre-programmed response from the material. Thus the material diagrams need to become dynamic as well, possibly using animations to illustrate the dynamic aspects of materials.

When designers begin to understand materials based on performance, it is only a small jump to a condition where specifications of materials will depend on performance characteristics and behavior. Materials can be developed, customized, or tuned for specific applications. Many new polymers and composites can be created out of a number of different materials placed within a matrix. By specifying the properties, the ingredients of the matrix could be created to return the required qualities specified. Conceptually, this might be similar to mixing paint - ingredients can be reverse engineered for a specific application.

3.5 *collaborative design*

Information and Presentation

Previous chapters have introduced the organization of data and the importance of the design process to material selection, this chapter builds on those ideas with the ability to visualize the data and the benefits that can be exploited through this visualization. According to one study carried out by Sandia National Labs, LBL, and Sci-tech Knowledge Systems in an article entitled “Materials Information for Science and Technology”, one of the main concerns of database users is, “the capability to quickly access and download data from materials property files and to be able to configure data in user-defined formats”. Once the visualization or the configuration of data in user-defined formats was understood as separate from the data itself, an additional level of flexibility was achieved in that the manipulation of the presentation did not affect the original data. The break between data and visualization allowed the user to restructure the data in order to represent it for particular situations or applications.

Reordering the Data

One method used to encode the intent of a user or a design team into the material property diagram was to reorder the material properties. A default ordering was based on the models presented in the Process Responsiveness and Inclusive Strategies chapters which grouped like terms together based on the discipline responsible for that information. A criticism of the default configuration of property terms was that it did not permit the properties to be weighted according to their importance. In response to this criticism, the option to give weight to properties was explored.

The relative importance of specific properties can be presented according to the properties' location around the diagram. The most important term occupies the top position on the diagram and is followed by the other terms in a clockwise manner, according to decreasing importance. The benefit of using a reordering strategy rested on the fact that the data was not manipulated, only the graphic. Reordering was the simplest method both to display and to understand the importance placed on properties.

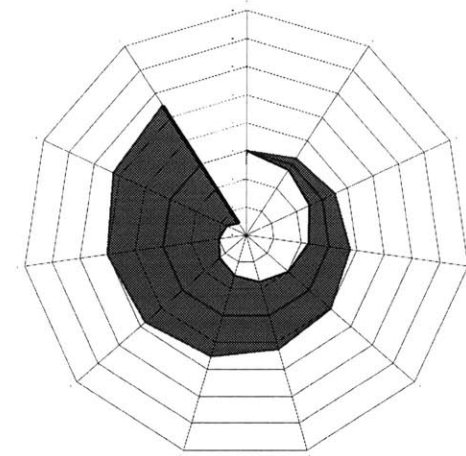


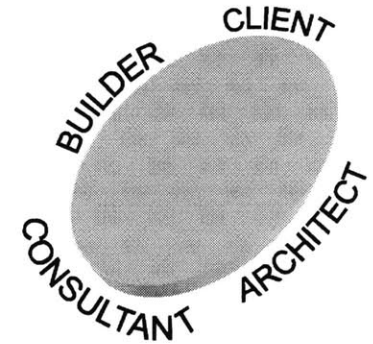
diagram showing range of acceptable values for re-ordered properties based on importance

Collaborative Tool

The ability to reconfigure the graphic output in conjunction with the comprehensive nature of the material selection process, described in chapter 3.3, permitted the exploration of the collaborative nature of a construction project through the material selection process. The fragmented nature of the construction industry creates conditions of high competition because specialized groups must protect their disciplinary boundaries. When collaborating with builders, consultants, designers, clients, and subcontractors (fig. 3.5.2) all of whom speak their own language, it is important to state goals and objectives explicitly with the intention of all working toward the same goal. The open, systemic nature of the material selection process that has been laid out, allows the many participants in the construction process to come together with one tool, discuss their own objectives and eventually set an agreed direction to follow. This coming together occurred by discussing the importance of different material aspects, the project team then agreed on an order for the project and stated this explicitly through the material selection chart.

There are two important aspects to the process of **ordering** material properties in association with working collaboratively. First, through collaborative work the ordering of material properties occurred dynamically. The importance of properties shifted as the project progressed. The material selection system allows for this dynamic flexibility. Second, the material selection system was able to track how the material property reordering process evolved. One can then retrace the decisions that were made throughout the duration of the project.

The ability to reorganize material properties through the diagram enabled the development of a dynamic design tool that focused on specific applications and aided in the selection of the correct material. This was the first step in empowering users to manipulate information in meaningful ways for specific instances. Reordering material properties also allowed for the ability to track the importance of different drivers for different applications - a structural application may have one set of parameters, while a facade component may have very different drivers in the material selection process.



3.5.2

interaction of multiple disciplines involved in collaborative process



Example 1 - Designer Responsive

To demonstrate the reconfigurability of the diagramming strategy, four designers were asked to rank the importance of the properties of glass. The properties were broad in nature to allow for a distribution of influences when exploring the glass as a material. This broad range of properties exposed the designers to the primary issues and allowed them to decide the degree to which these issues were important.

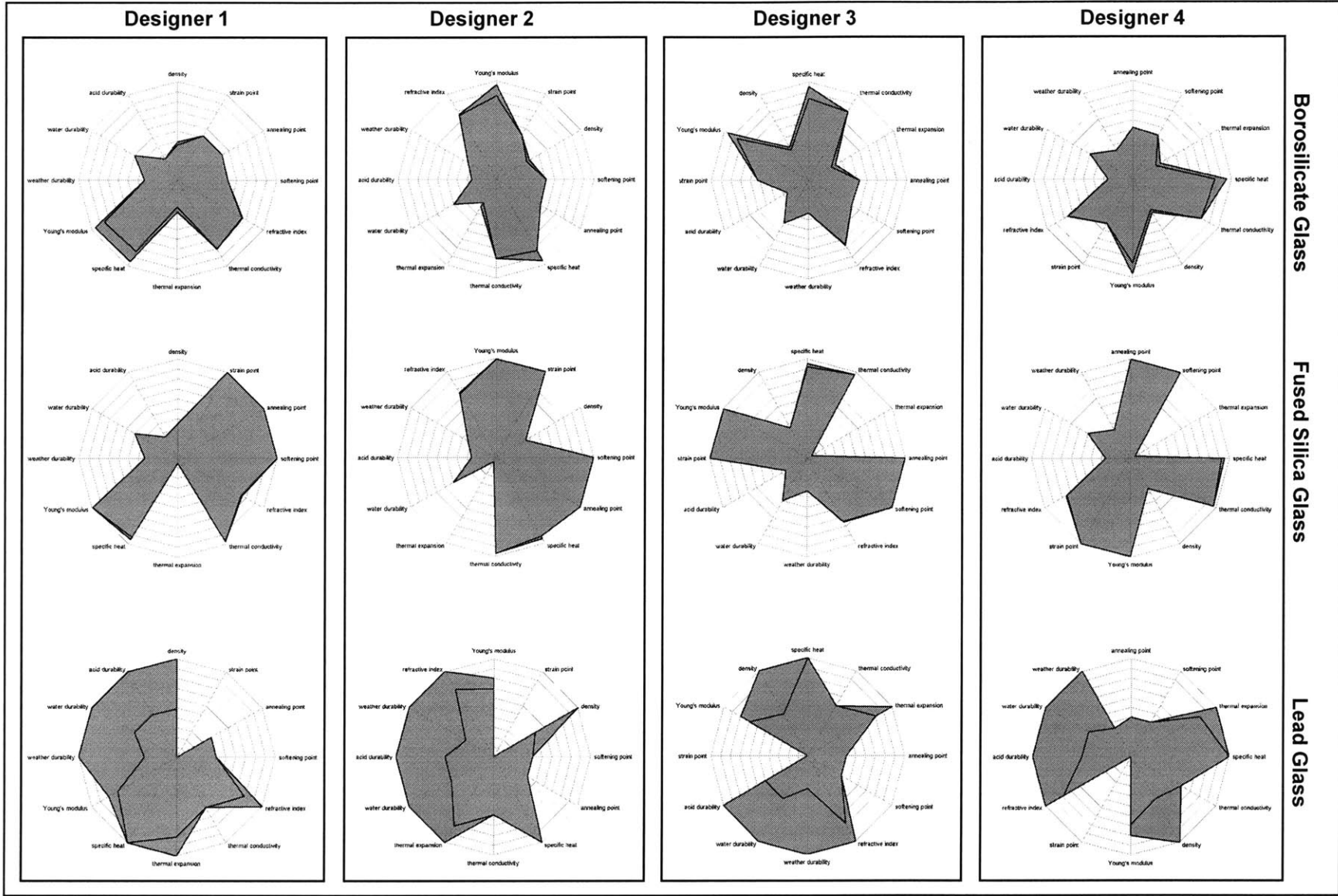
On the following page a matrix is presented that contains three types of glass, organized according to the weighting of four different designers. Designer1 was most concerned with structural issues, then production, optical, and thermal issues, while being least concerned with durability. Designer2 had similar concerns except for considering optical quality the least important issue. Designer3 placed the strongest emphasis on thermal, optical, and durability, making structure the least important issue. Designer4 ranked production and thermal issues the highest, while ranking optical and durability the least important concern.

Using the ranking orders of the four different designers, property profiles were generated for the three types of glass: borosilicate glass, fused silica glass, and lead glass. When comparing the material's properties using this method for reordering, the most appropriate material is the one with high values between twelve and six o'clock. Values for the rest of the properties usually become an issue only if materials are similar up to that point in the graphic.

According to the results from designer1 the most appropriate choice appears to be fused silica glass. Lead glass, although full in its graphic, presents low values in the issues important to the designer. For designer3, the selection is not as clear; both fused silica and lead glass present high property values ranked as important. The designer would need to balance between glass with a higher thermal conductivity and glass with higher thermal expansion.

diagrams of three materials based on the order of importance placed on different material properties

3.5.3





Conclusion

At the beginning of the research, the material visualization system seemed to be a static method to map materials, meaning that once a material was mapped the diagram would not change. This was considered analogous to the way food and drugs can be compared based on the ingredients and nutrition. One type of food can be compared to another quite easily because all the terms of comparison are understood. Making the materials selection process designer responsive posed an interesting problem: the diagrams needed to change. They became dynamic because they were prepared for different situations and applications. It became a compelling way to understand the data, putting the real control not with the creators of the database, but giving the power to the users, the designers. The data was not as important as the interpretation of the data. With the understanding gained from reordering the charts, the notion of capturing information from these situation specific configurations lead to the research on the design profile (see chapter 3.6).

Future Work

A specific trajectory for further research could be the use of this type of design responsive tool in practice. It is necessary to understand the implications that this type of tool could have on how a team communicates and collaborates. Specific case studies can be carried out, either in a design studio setting or with “real world” project teams to trace the decisions that designers place on material properties.


Design Profiles

The research into the design profile was an important aspect which transformed the project from an act of mapping material properties into a strategy for selecting appropriate materials for specific applications. The goal of having a designer input a design profile was to create interaction between the designer and the material selection system. The presentation of material information was understood as a passive activity. In contrast, the system became more dynamic as the interface made use of information input by a designer. This designer input was then compared the material properties.

Profile Evolution

According to Olsson, "the designer has to define a demand profile for the product to be developed and to find a material offering a matching property profile. Very likely the demand profile will be revised several times during the progress of the work leading to revised material selection" [Olsson, 1980]. The revision of the demand profile is related to many of the aspects discussed in Chapter 3.2 (Process Responsiveness), because it is an important aspect of the design process. Initial assumptions are made, tested, and refined. As more information is made available, more decisions can be made. This process then concludes with the selection of a material.

The design profile acted as a secondary layer of information that was based on input from the designer for specific applications. It became not only a datum against which the material data could be read but it became a way to input project or application specific information into the data matrix. Building on the notion of the evolution of the design profile, the appropriateness of a material in relationship to the design profile became a subjective criteria for the designer to specify. For example, a material with a property below the design profile is 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. A premium may be paid for the high performance of that one material property. 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 property.



There are two reasons why the user refined the design profile: invalid input value or obsolete input value. The first condition was apparent when no materials were returned from the database because the value was out of the range. The designer then revised the value or investigated why the specified value was so extreme. If the value was correct, the designer then explored other options for achieving the specified level of performance. One solution to increase performance of material aspects could be achieved through combinations of materials or components. The second reason why a designer would want to refine the design profile is that more specific knowledge related to the application has been uncovered. This new knowledge renders the previously specified value obsolete. The value was then increased or decreased because the level of performance was previously over or under specified. It is through this type of interaction between designer and database that a dynamic interface has been created.

The belief is that as a larger database is assembled, the design profile can be used as the search mechanism to return material options. The user can specify a viable range based on a percentage of how close material properties must match the design profile. These variables for viability should 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 design profile could become a critical method for specifying aspects of dynamic material properties. The user would have the ability to input a range of the properties for the material, such as a maximum and minimum value for transparency or stiffness. External conditions that bring about such a change could also be specified, such as the temperature at which a material transforms. The input specifications could be taken to a level where designers specify the type of material transformations that should occur.



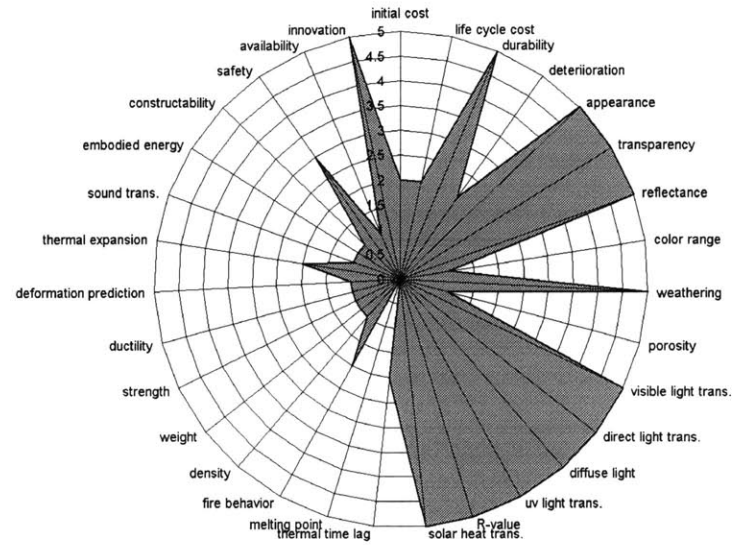
Plotting Designer's Intent

The inclusion of the design profile creates another way for a designer to be explicit about the intent for the application of a material. In combination with the ability to reorder the properties of the materials, the design profile can be used by a project team to state their desired performance for a material or a component. The intent can become more specific by the designer including notes such as, "not to exceed a certain value" or "to be less than a specific value".

An early study that explored the input of a designer involved the selection of materials for the North facade of a science museum. To make the process easy for the designer, a questionnaire was created that asked simple questions about the desired performance of materials for this particular application. The designer simply had to give an answer on a scale of zero to five. These values were then compiled and plotted the same way the materials have been plotted (fig. 3.6.1). Information about the intent became a valuable resource for consultants working under the designer, giving them direction for decisions. The graphics to the right show the same data, the only aspect that has been changed is the order, figure 3.6.2 illustrates the reorganization concept described in Chapter 3.5, Collaborative Design.

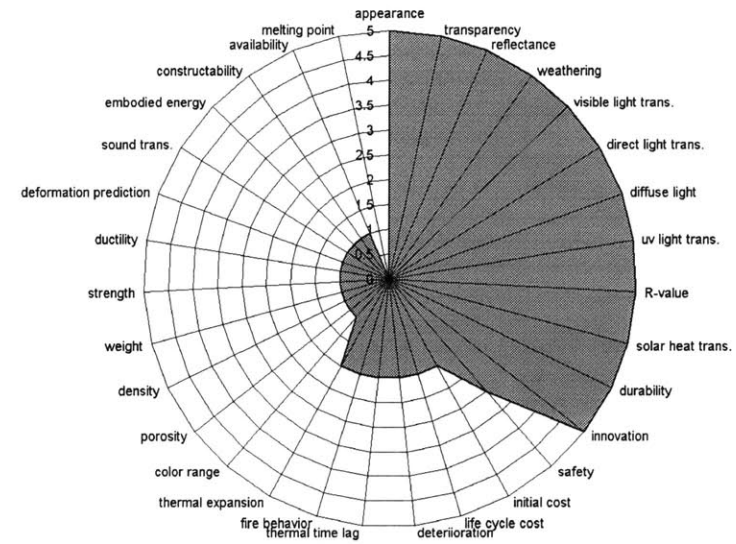
This ability to capture intent can become a valuable resource for all types of people involved in the construction process. As buildings become more complex, sophisticated, and intelligent, this type of information can be used by the client years after the building has been constructed. In the case of a material failure, the client can quickly understand why the material was selected and replace it with a material that closely matches the intent of the designer - even if the material is different. In this scenario, the new material will not work contrary to a specific goal of the design, which, if not understood, could cause a decrease in the performance of the building.

3.6.1



plotting of importance of material properties by designer using the profile mapping technique

3.6.2



reorganization of material properties based on the level of importance



Example 1 - Profile Overlay

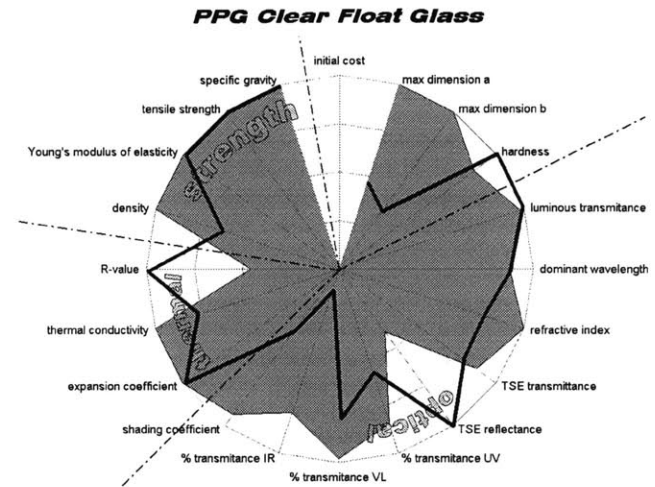
This example made use of a material database that was developed for the comprehensive comparison of glass produced by PPG. The terms used at this level such as thermal, mechanical, and optical properties were specific to glass. The solid area of the charts to the right are the property profiles of the specific materials, produced from the material database. The values and areas of the chart were understood as static elements because they represent the materials, which do not evolve over the course of the design.

The black line representing the design profile, on the other hand, became a highly dynamic and interactive aspect of the material selection process. This line was created from the values that were input by the designer specifying the values of properties that they hoped to achieve in a material for a particular application. This line then became 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.

This example compared a clear float glass with a body tinted glass. The design profile was the same for both materials, with the material property values varying from one chart to the next. According to the charts, three conditions existed between the design profile and the material property values, matching, below and above. The first condition where the profile and properties match can be seen on both materials for Young's modulus of elasticity, tensile strength, and specific gravity. A condition where the material is below the desired value is for R-value. The desired R-value for the material was specified as "2", the clear float glass has a value of ".91" and the Azurlite glass a value of ".92". The third condition where the material values exceed the desired value occur at the maximum dimensions; the application requires a window of "48inches x 96inches", both glass types are available in sizes up to "130inches x 204inches". The values for the dimensions would not have to be refined as the key issue is that the desired size is not larger than the maximum available dimensions.

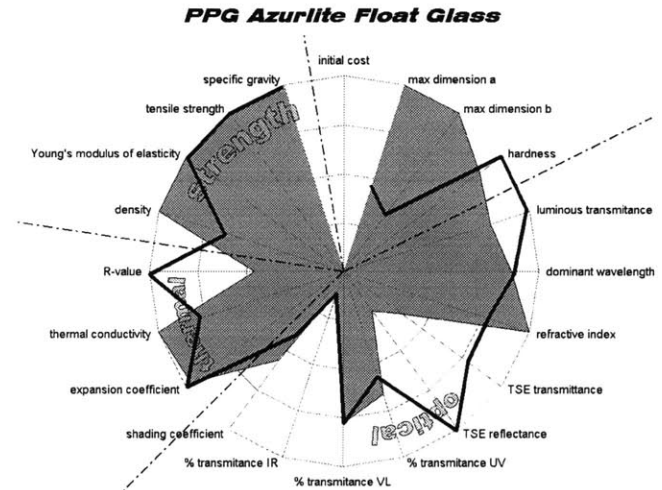
Many of the other relationships of designer's intent and property profile vary between the two charts. The differences of the two charts allow the designer to choose one over the other based on the material / design profile relationship.

3.6.3



designers intentions (black line) overlaid on property profile for clear float glass

3.6.4



designers intentions (black line) overlaid on property profile for float glass with a coating

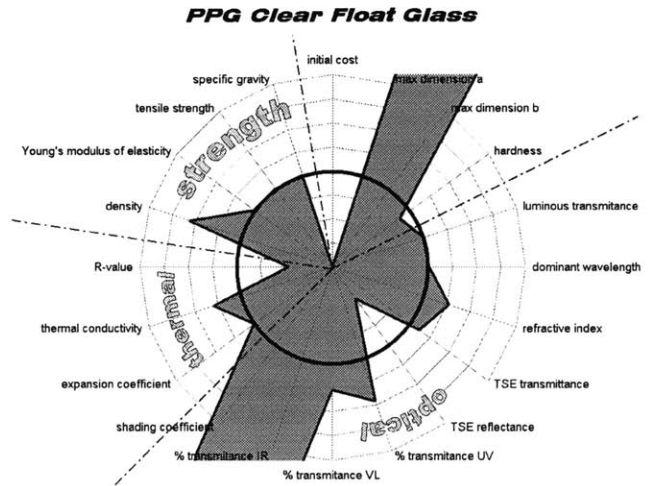


Example 2 - Profile-centric

This investigation with the design profile takes an inverse approach in comparison to Example One 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 examples presented with these profile-centric diagrams use the same design input and material data as the profile overlay diagrams, however the method used to present the information differs.

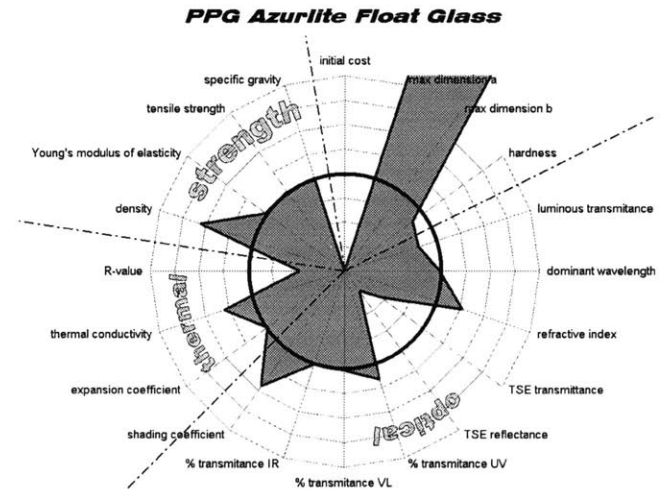
The design profile becomes a simple circle that represents 100%. The material values are then compared to the specified values and a percentage is calculated. Similar to the last example. Young's modulus, tensile strength, and specific gravity match the desired design profile. The R-value for both materials is about 46% less than the design value (.91/2). And again the available sizes of the material far exceed the desired sizes by more than 200% for each dimension.

This type of profile centric representation proved to be visually more easy to understand because it eliminated the complexity created by the competing lines of the material properties and the design profile. This example 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, making this operation more designer specific. This specificity of designer application works counter to the belief that this type of visualization strategy could be universally employed for all materials, making an argument that mapping material properties with design profiles should be done for specific projects or applications.



3.6.5

property profile for clear float glass reorganized according to designers intentions (black line at center)



3.6.6

property profile for float glass with coating reorganized according to designers intentions (black line at center)



Conclusions

The design profile added a more refined level of interactivity to the use of the material selection method. The design profile built upon the notion that the database existed in the background and the display of the data was actively manipulated by the user. The first attempt at plotting the design profile [Example One] acted simply as a registration line against which the presentation of the material information could be considered. Through continued work with the overlay method, one concern was that the graphic became too complex and may have been working against the goal of visual clarity. Example Two treating the profile as a benchmark which simplified the graphic quality of the diagram. The material data was then presented based upon the profile values. This data operation employed a relative strategy which plotted the data values as a percentage of the design value. Visually clearer, this technique also makes the material chart more easily understood since the plots of material and profile did not compete against one another.

Future Work

This area of the thesis can develop into two important research endeavors, both of which are related to knowledge management. The first investigation is to record the evolution of real world test case design profiles and begin to compare them against one another. This will begin to map trends and patterns of material selection as well as to give vital information regarding where and when compromises are made for material selection. This information may be of value to the material production industry by aiding them in decisions about which values need to be optimized for better performance.


The second area of research that could be explored in more detail is the ability to record design profiles and save them related to the application for which they have been developed. This could create a “toolbox” of predefined application profiles that can be used either as a guide for designers that lack experience or as a starting point in the process. Important issues could be documented such as the design profile of a facade component or the profile of a structural element. Designers could use these predefined profiles as a reference to compare with the performance they are specifying in an effort to streamline the material selection process.

4.0

conclusions

Three general conclusions have been made regarding the implementation of the material selection process described in this work. First, a need exists for it. Second, it has the potential to aid designers in the selection of materials. And third, it can be applied to assess broader issues associated with architectural design. The need for such a material selection process was clearly proven by the difficulties encountered while attempting to acquire hard material data from manufacturers. Further complications arose due to the fact that much of the data was not comparable, since values, terms, and testing methods are not standardized. An appropriate material selection process should "run in the background" and enable designers to directly do the job of selecting the correct materials for the right application. Budgets and design fees are too limiting for a designer to spend more than a very limited amount of time attempting to get information on new materials, let alone information on familiar materials. Unknowingly, material suppliers are creating a barrier to innovation because designers can not access the necessary information in a reasonable amount of time. Any designer in such a position would select a familiar material, instead of trying to acquire new product information, saving time to resolve design issues.

This research proves that an appropriate environment for making informed material decisions must distill and filter relevant data and present the information to the designer in a visual manner. This has been proven both in academic and practical settings. The goal was never to create an entire database for materials, but instead to propose a strategy for understanding complex design problems. This strategy has been validated conceptually through discussions with students, designers, and theoreticians concerned with new materials. In this setting the material selection strategy aids in the understanding of the complex issues of smart materials that exhibit dynamic behavior. The material selection strategy has also been used in practical applications by the Ove Arup R+D materials group to help clients decide which material or product may be the most applicable for a specific situation (see example 3.2). In this setting the strategy was used to understand complex issues associated with issues of collaboration and the appropriate application for materials. It has been a rewarding experience to hear the advantages and disadvantages from someone using the strategy, and be able to incorporate the comments into the ongoing research.



The focus on material selection has made four main contributions to advancing the research. It provided a platform to explore broader issues within design and present a vision of how this material selection system may fit into the larger scheme of the design process. This research also allowed for the exploration of the relationship between data and the graphic display of information - a topic that is becoming increasingly relevant as more information is made public and accessible. Moreover, this research permitted the exploration of material influence on design. The research proposes the use of simulation and visualization tools as a method to extend the influences of materials in design by allowing designers to computationally test situations without having to physically construct them. Finally, this research permitted the investigation of hybrid systems in architecture. In this setting, hybridity is achieved through the various types of information, data, disciplines, and representation techniques. The thesis work proposes a strategy to synthesize a number of discrete and diverse elements into one coherent and comprehensive system.

This research is not meant to stand alone but rather to be incorporated into an object-oriented CAD package. This incorporation would be beneficial in that the material selection strategy could be used to assign material properties to CAD objects. The overall design can then be studied, analyzed, and simulated using many different types of simulation engines that are able to access the object properties. This strategy should provide the process for a designer to constantly explore material issues throughout design and allows materials to become a true catalyst for architectural design.

This research was an opportunity to test ideas about design as a synthetic activity. The concept of synthetic design contrasts directly with the idea of a lead system in which one parameter is optimized and used as the criteria for making decisions. The material selection process as documented uses multiple parameters for design, synthesizing many influences such as construction, economics, performance, and aesthetics. In this case, materials provided the focus, inspiration, and complexity for a meaningful exploration of design because such an abstract idea needs to be focused around a topic that can be studied in a certain time frame.

The final task is to re-map the research to the broader issues that were the initial inspiration for the investigation such as multidisciplinary interaction in design and multivariable synthesis as a generator of building form. The goal is to now put the thinking into action.

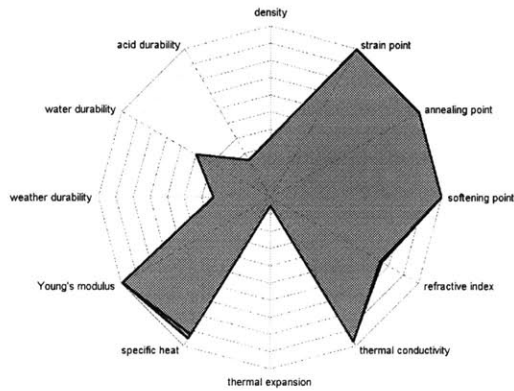
5.0

appendix 1

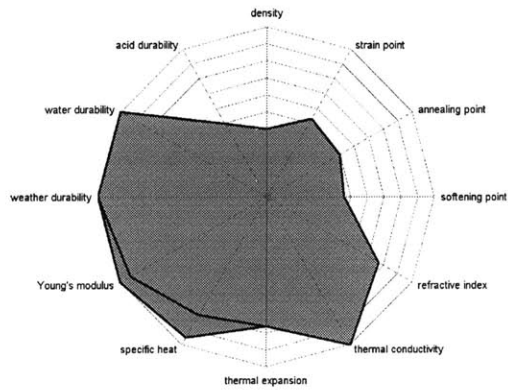
The appendix consists of boards that were developed over the course of the project to address specific issues.

GLASS ANALYSIS

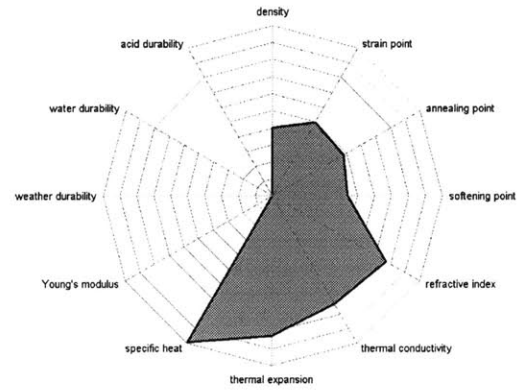
FUSED SILICA GLASS



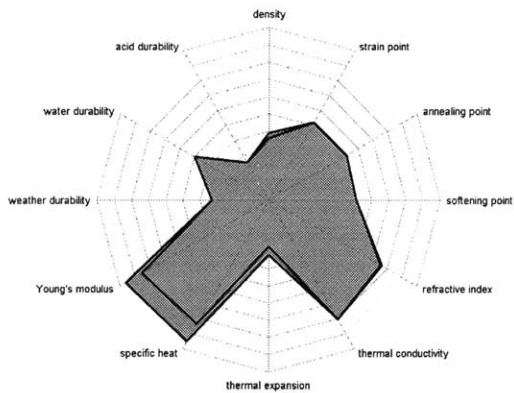
SODA-LIME GLASS



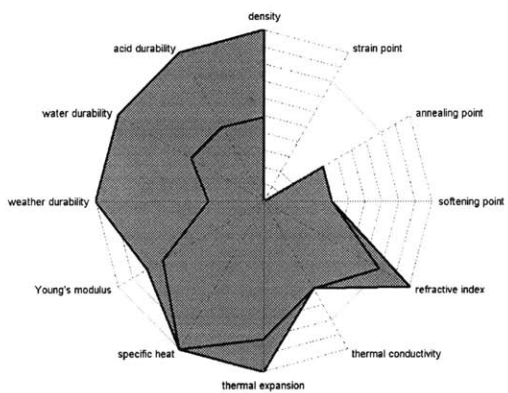
FLOURESCENT TUBE GLASS



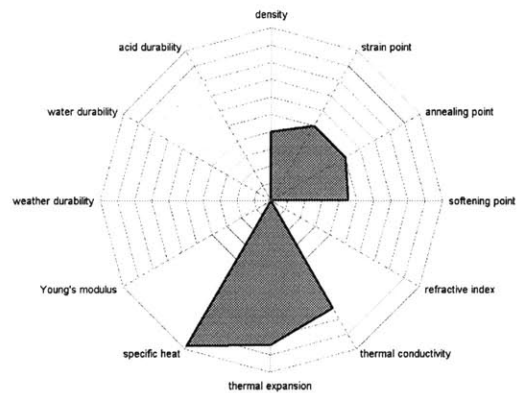
BOROSILICATE GLASS



LEAD GLASS



CONTAINER GLASS



Density: weight per unit volume

Strain Point: temperature above which stress release and flow become important characteristics

Annealing point: temperature at which stresses in the glass are quickly relieved

Softening Point: temperature at which the glass becomes soft enough to flow

Refractive Index: measure of the degree to which a glass reflects light at each surface

Thermal Conductivity: quantity of heat transmitted in a unit of time, due to a temperature gradient, under steady conditions in a direction normal to a surface of a unit area

Thermal Expansion Coefficient: increase in length per unit length the material expands for every degree C increase in temperature

Specific Heat: amount of heat necessary to raise a unit weight of material through 1 degree C

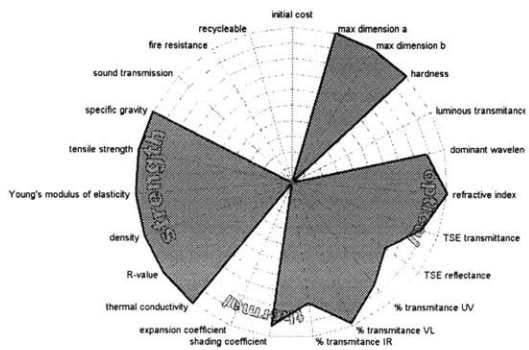
Young's Modulus: stress / strain

Durability: general indications for weathering resistance in decreasing order from 1 to 4

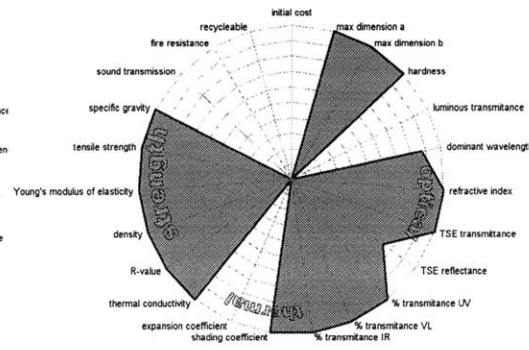
Note: Technical data taken from table 40 page 269: [Glass in Architecture](#)

clear body

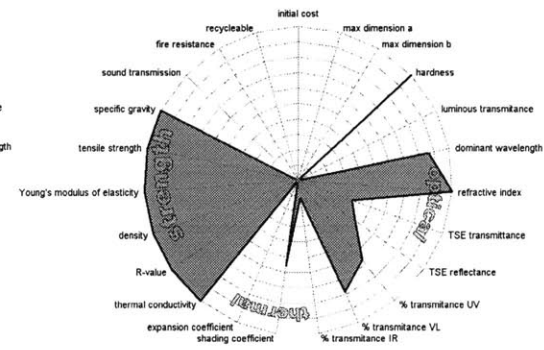
PPG Clear Float Glass



PPG Starphire Float Glass

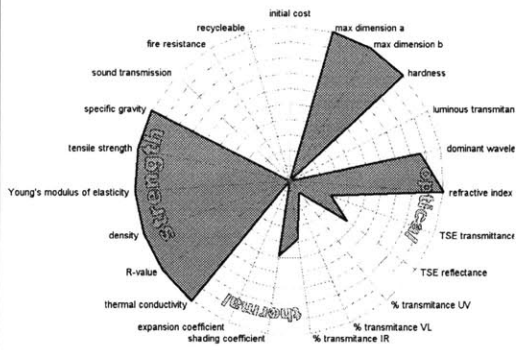


PPG Azurlite Float Glass

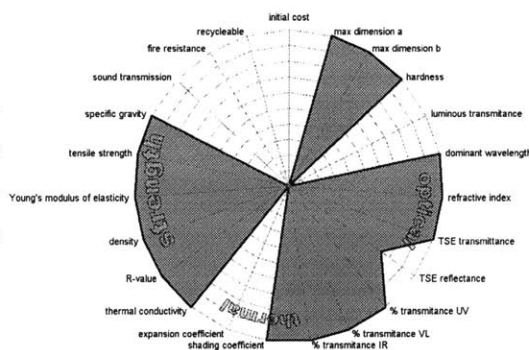


coatings

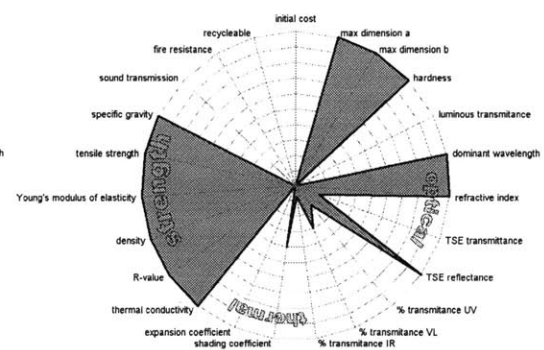
PPG Greylite Float Glass



PPG Solarcool Coated Azurlite Float Glass (1)



PPG Solarcool Coated Azurlite Float Glass (2)

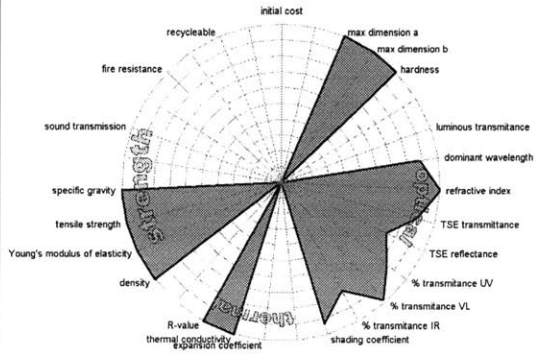


PPG GLASS ANALYSIS 1

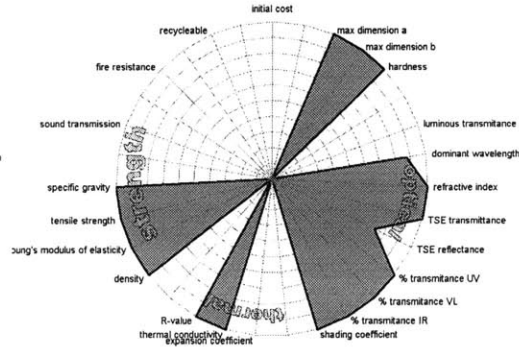
clear

body

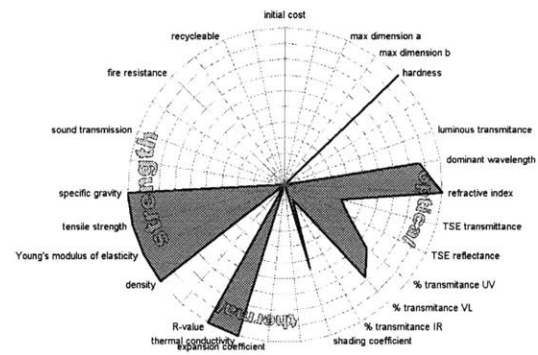
PPG Clear Float Glass



PPG Starphire Float Glass

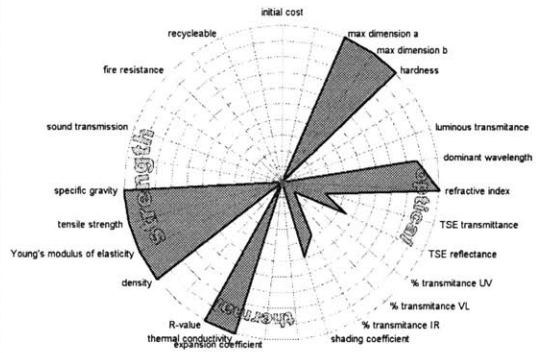


PPG Azurlite Float Glass

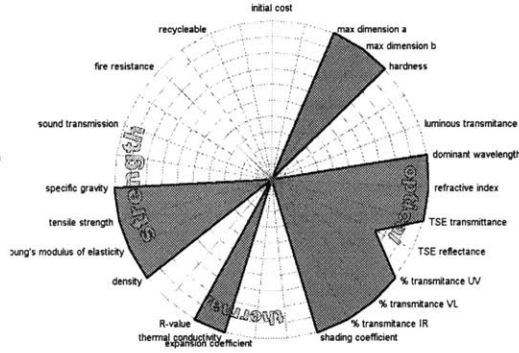


coatings

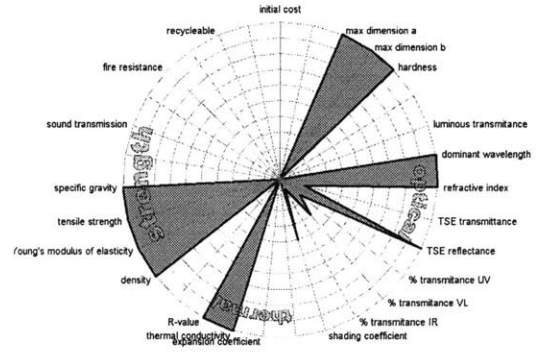
PPG GreyLite Float Glass



PPG Solarcool Coated Azurlite Float Glass (1)



PPG Solarcool Coated Azurlite Float Glass (2)

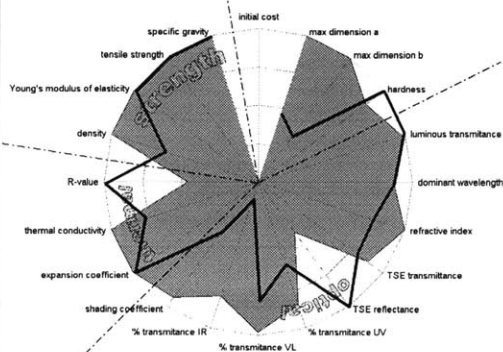


PPG GLASS ANALYSIS 2

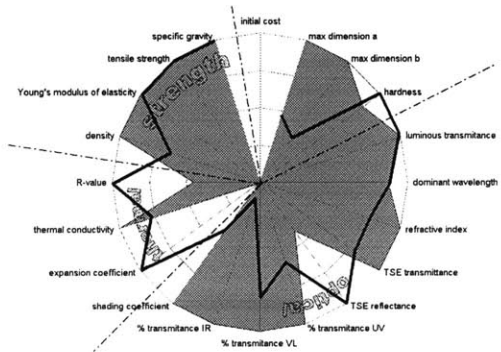
clear

body

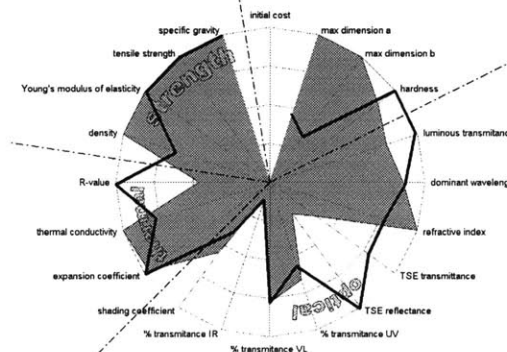
PPG Clear Float Glass



PPG Starphire Float Glass

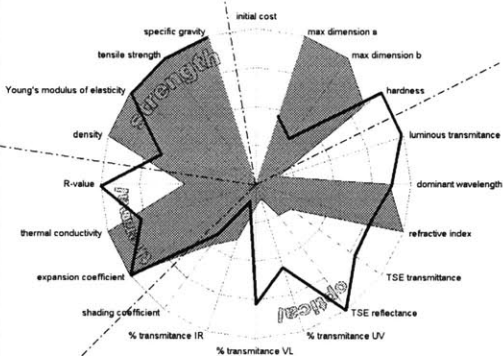


PPG Azurlite Float Glass

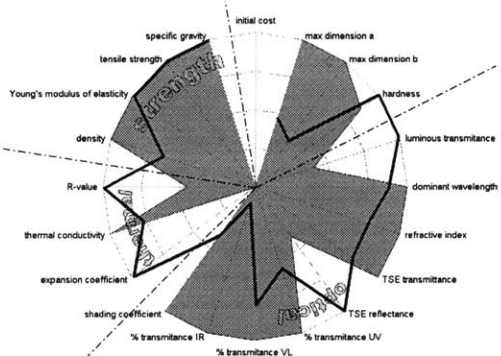


coatings

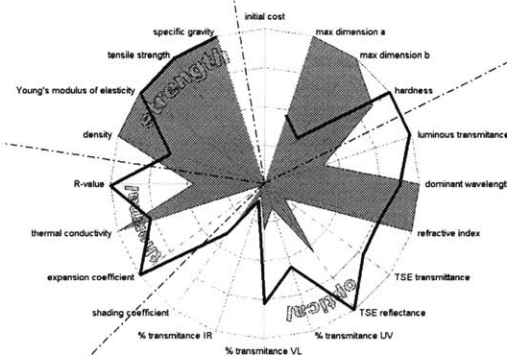
PPG Greylite Float Glass



PPG Solarcool Coated Azurlite Float Glass (1)



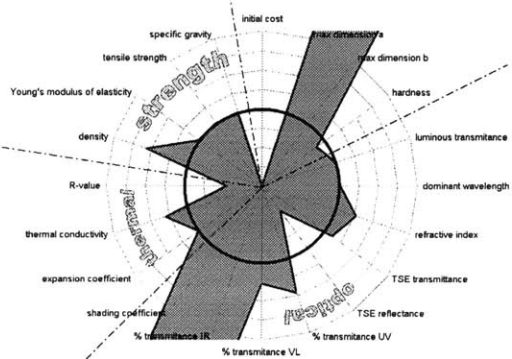
PPG Solarcool Coated Azurlite Float Glass (2)



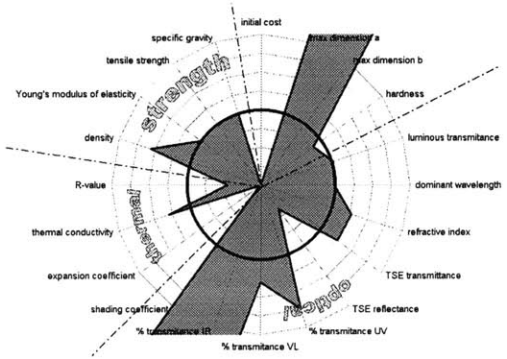
DESIGN PROFILE 1

clear body

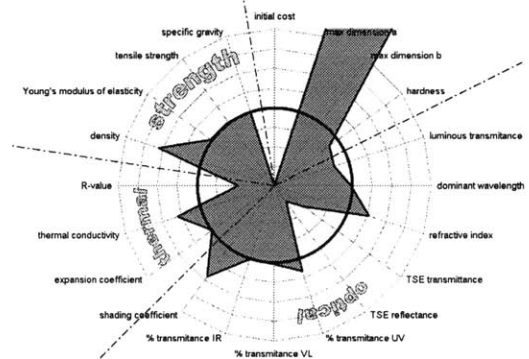
PPG Clear Float Glass



PPG Starphire Float Glass

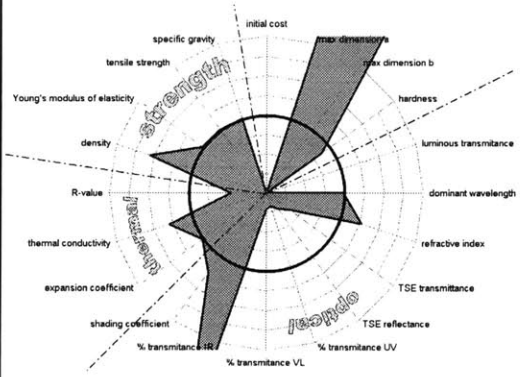


PPG Azurlite Float Glass

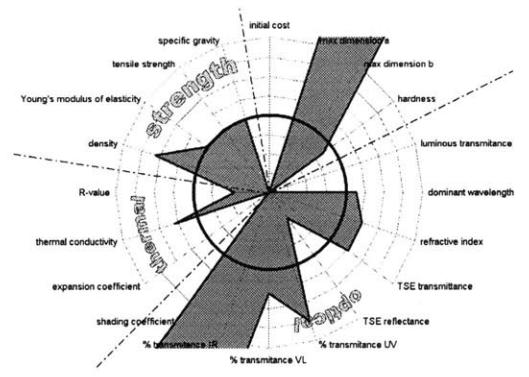


coatings

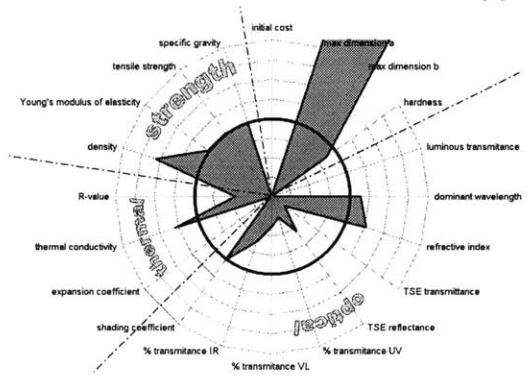
PPG Greylite Float Glass



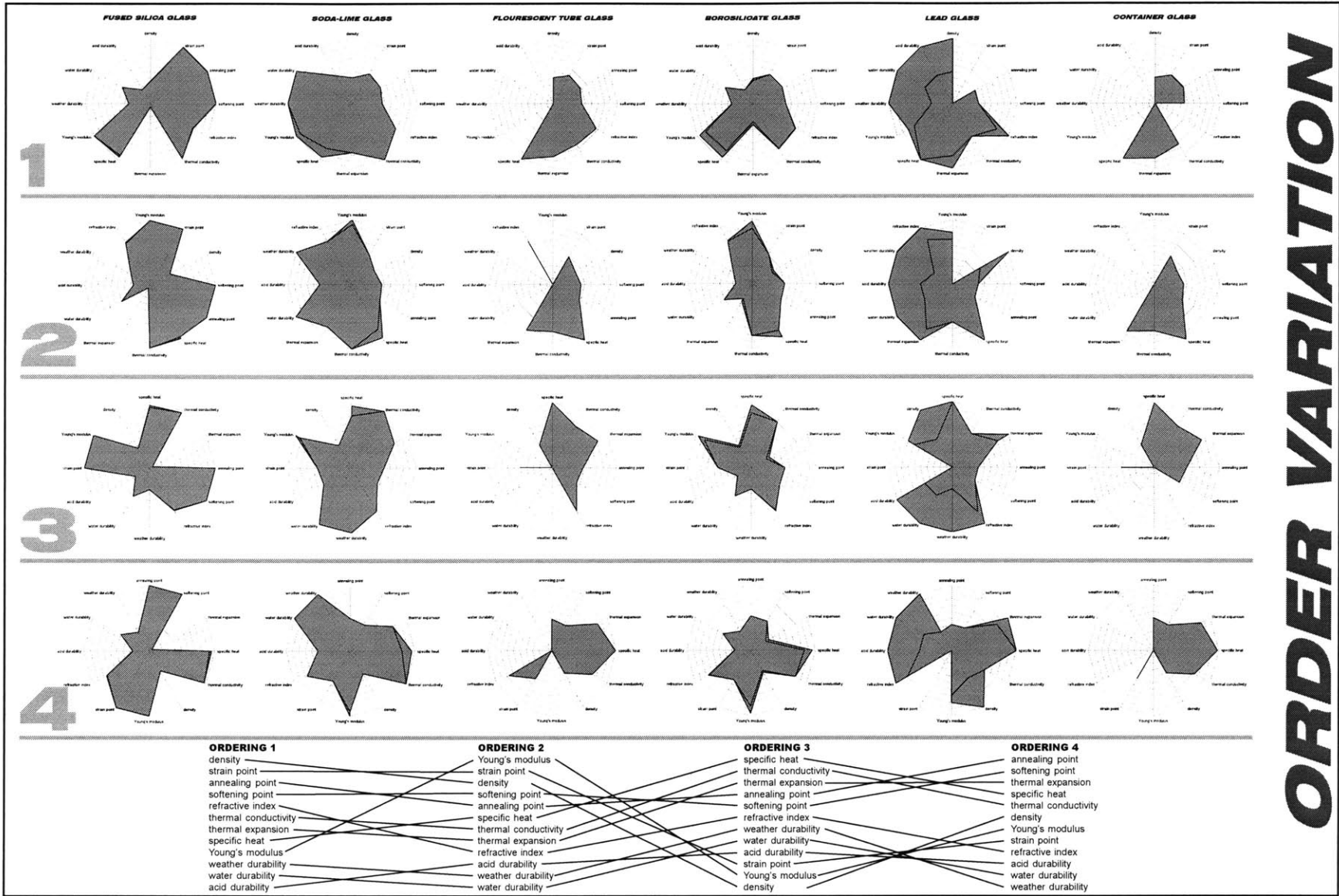
PPG Solarcool Coated Azurlite Float Glass (1)



PPG Solarcool Coated Azurlite Float Glass (2)



DESIGN PROFILE 2



ORDER VARIATION


6.0

list of illustrations

title page: computer rendering by Karl Daubmann

- 1.1 Stonehenge photo by Karl Daubmann
- 1.2 Renault Center photo by Karl Daubmann
- 1.3 Wright Brothers Airplane courtesy of National Air and Space Museum, Smithsonian Institution, Washington, D.C.
- 1.4 B2 Bomber photo from USAF by by MSgt. Rose Reynolds
- 1.5 Palazzo Farnese photo by Karl Daubmann
- 1.6 SUVA Insurance Building photo by Karl Daubmann
- 1.7 Darkened suspended particle device photo from Research Frontiers Inc. <<http://www.refr-spd.com/hgi-window-f.html>>
- 1.8 Lightened suspended particle device photo from Research Frontiers Inc. <<http://www.refr-spd.com/hgi-window-f.html>>
- 1.9 E.W. Gilbert, "Pioneer Maps of Health and Disease in England", Geographical Journal, 124 (1958), 172-183.
- 1.10 E.J.Marey, *La Method Graphique* (Paris, 1885), p.20
- 1.11 computer rendering by Karl Daubmann
- 1.12 image by Karl Daubmann
- 1.13 computer rendering by Karl Daubmann
- 1.14 computer rendering by Karl Daubmann
- 1.15 computer rendering by Karl Daubmann
- 1.16 computer rendering by Karl Daubmann
- 1.17 computer rendering by Karl Daubmann

- ss2.1 screen shot from <http://www.materialconnexion.com>
- ss2.2 screen shot from <http://www.materialconnexion.com>
- ss2.3 screen shot from <http://www.materialconnexion.com>
- ss2.4 screen shot from <http://www.sweets.com/index.htm>
- ss2.5 screen shot from <http://www.sweets.com/index.htm>
- ss2.6 screen shot from <http://www.sweets.com/index.htm>
- ss2.7 screen shot from <http://www.sweets.com/index.htm>
- ss2.8 screen shot from <http://www.designinsite.dk>
- ss2.9 screen shot from <http://www.designinsite.dk>
- ss2.10 screen shot from <http://www.designinsite.dk>
- ss2.11 screen shot from <http://www.designinsite.dk>
- ss2.12 screen shot from <http://www.designinsite.dk>
- ss2.13 screen shot from <http://www.designinsite.dk>
- ss2.14 screen shot from <http://www.supplieronline.com>
- ss2.15 screen shot from <http://www.supplieronline.com>
- ss2.16 screen shot from <http://www.supplieronline.com>


- 
- 2.3.1 diagram from Material Selection in Mechanical Design by M.F. Ashby p.25
 - 2.3.2 material chart from Material Selection in Mechanical Design by M.F. Ashby p.28
 - 2.3.3 material chart from Material Selection in Mechanical Design by M.F. Ashby p.50

- 2.4.1 diagram by Karl Daubmann
- 2.4.2 diagram by Karl Daubmann
- 2.4.3 diagram by Karl Daubmann

- 3.0.1 diagram by Karl Daubmann
- 3.0.2 diagram by Karl Daubmann

- 3.1.1 diagram by Karl Daubmann
- 3.1.2 screen shots from Pilkington <<http://www.pilkington.com/js.htm>>and PPG <<http://www.ppgglass.com>>
- 3.1.3 diagram by Karl Daubmann
- 3.1.4 diagram by Karl Daubmann
- 3.1.5 diagram by Karl Daubmann

- 3.2.1 diagram by Karl Daubmann
- 3.2.2 diagram by Karl Daubmann
- 3.2.3 diagram by Karl Daubmann
- 3.2.4 computer rendering by Karl Daubmann
- 3.2.5 diagram by Karl Daubmann
- 3.2.6 diagram by Karl Daubmann
- 3.2.7 diagram by Karl Daubmann
- 3.2.8 diagram by Karl Daubmann
- 3.2.9 computer rendering by Karl Daubmann
- 3.2.10 computer rendering by Karl Daubmann
- 3.2.11 diagram by Karl Daubmann
- 3.2.12 diagrams by Ove Arup and Partners Research and Development - Materials Group

- 
- 3.3.1 diagram by Karl Daubmann
 - 3.3.2 diagram by Karl Daubmann
 - 3.3.3 diagram by Karl Daubmann
 - 3.3.4 diagram by Karl Daubmann
 - 3.3.5 diagram by Karl Daubmann
 - 3.3.6 diagram by Karl Daubmann

- 3.4.1 diagram by Karl Daubmann
- 3.4.2 diagram from Glass in Building p.130
- 3.4.3 diagram from Glass in Architecture p.265
- 3.4.4 diagram by Karl Daubmann
- 3.4.5 photo from Lawrence Berkley Nation Labs <<http://eande.lbl.gov/ECS/aerogels/KEVIN.JPG>>
- 3.4.6 diagram by Karl Daubmann
- 3.4.7 diagram from Glass in Architecture p.265
- 3.4.8 diagram by Karl Daubmann
- 3.4.9 diagram from Intelligent Glass Facades p.73
- 3.4.10 diagram by Karl Daubmann
- 3.4.11 diagram from Glass in Architecture p.265
- 3.4.12 diagram by Karl Daubmann
- 3.4.13 diagram by Karl Daubmann
- 3.4.14 diagram by Karl Daubmann

- 3.5.1 diagram by Karl Daubmann
- 3.5.2 diagram by Karl Daubmann
- 3.5.3 diagram by Karl Daubmann

- 3.6.1 diagram by Karl Daubmann
- 3.6.2 diagram by Karl Daubmann
- 3.6.3 diagram by Karl Daubmann
- 3.6.4 diagram by Karl Daubmann
- 3.6.5 diagram by Karl Daubmann
- 3.6.6 diagram by Karl Daubmann

7.0


bibliography

7.1 Analysis and Visualization

- Edmondson, Brad. "The Place Rating Game." Attache (November 1998): 72 - 78.
- Tufte, Edward R. Visual Explanations. Cheshire, Connecticut: Graphics Press 1997.
- Tufte, Edward R. Envisioning Information. Cheshire, Connecticut: Graphics Press 1990.
- Tufte, Edward R. The Visual Display of Quantitative Information. Cheshire, Connecticut: Graphics Press 1983.
- Groak, Steven. "Representation in Building." Ted Happold Memorial Lecture: 18 February 1998.
- Wurman, Richard Saul. Information Architects. New York, NY: B. Martin Pedersen and Richard Saul Wurman Publishers - Graphis Inc. 1997.

7.2 Materials

- Addington & Shodek. New Technologies in Design. Class 6400 offered at Harvard Graduate School of Design, Spring 1999.
- Addleson & Rice. Performance of Materials In Building. Oxford: Butterworth-Heinemann 1991.
- Ashby, M.F. Materials Selection in Mechanical Design. Oxford ; Boston: Butterworth-Heinemann 1995.
- Cardwell, Cather & Groak. "New Materials for Construction." The ARUP Journal vol 32 no 3 (March 1997): 18-20.
- Cornish, E.H. Materials and the Designer. Cambridge: Cambridge University Press 1987.
- Dunster, David. ed. Arups on Engineering. Berlin: Ernst & Sohn. [66 - 73 O'Brien, Turlogh. Materials Science In Construction.

- 
- Forester, Tom. The Materials Revolution. Cambridge, MA: The MIT Press 1988.
- Frauenfelder, Mark. "Smart Parts." Wired vol 6 no 8 (August 1998): 112 - 113.
- Gandhi & Thompson. Smart Materials and Structures. London: Chapman & Hall 1992.
- Kaufman, J.G. "The National Materials property Data Network Inc. The Technical Challenges and the Plan". Materials Property Data: Applications and Access. New York: The American Society of Mechanical Engineers 1986.
- Northrup, McCarthy, Westbrook & Grattidge. "Materials Information for Science and Technology - A Prototype Material Properties Data Network System". Materials Property Data: Applications and Access. New York: The American Society of Mechanical Engineers 1986.
- Olsson, Bengtson & Fischmeister. "Computer Aided Materials Selection." Computers in Materials Technology. Sweden: Linkoping University 1980.
- Sheehan, Tony. "Smart material in construction: Dream or reality?" The ARUP Journal vol 32 no 4 (April 1997): 32-35.

7.3 Glazing

- Button & Pye. Glass in Building. Oxford: Butterworth Architecture 1993.
- Compagno, Andrea. Intelligent Glass Facades. Basel, Boston, Berlin: Birkhauser Verlag 1995.
- Flat Glass Marketing Assoc. Glazing Manual. Topeka: Flat Glass Marketing Association 1990.
- Johnson, Timothy. Low-E Glazing Design Guide. Boston: Butterwoth Architecture 1991.
- Krewinkel, Heinz W. Glass Buildings - Material, Structure and Detail. Basel, Boston, Berlin: Birkhauser Verlag 1998.
- McEvoy, Michael. Mitchell's External Components. Essex: Longman Scientific & Technical 1994.
- Wigginton, Michael. Glass in Architecture. London: Phaidon Press Ltd. 1996.