

**The Systems Phenomenon in Buildings and its
Application to Construction Specifications**

by

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B.Arch., University of Notre Dame du Lac (1989)

Submitted to the Department of Architecture
in partial fulfillment of the requirements for the degree of

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at the

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Abstract

This thesis proposes that the holistic quality of a building can be improved by modifying the way that it is represented in the specifications document. It develops a construction specifications format based on a substantive rather than a procedural division of the building, i.e., on a division according to the interrelationships between the physical parts of the building rather than according to the administration of labor in the construction process.

In communicating a design idea in the construction documents, the architect should represent the building not as a collection of independent parts to be procured and installed, but as a whole *system* consisting of many perceptually and technically integrated parts. The documents should communicate the essence of the whole building through the format of their presentation. In drawings this is accomplished by portraying the parts of the building as images organized on paper in the same geometrical relationships that they are to take in the finished building. Construction specifications should also possess a strong relationship to the form of the whole building that they describe.

Hypertext computer software offers great flexibility in both the authoring and in the reading of text documents. This thesis uses Hypercard to develop a format for construction specifications documentation.

Thesis Supervisor: Eric Dluhosch
Title: Professor of Architecture

A building's message is the fact.

–Konrad Wachsmann

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Contents

1	Introduction: <i>What a Building System is and What it has to do With Construction Specifications</i>	19
2	The Observer and the Environment	33
2.1	Visual Perception Theory	33
2.2	The Dialogue of Visual Experience	39
2.2.1	Subjective Contours and Phenomenal Transparency	40
2.2.2	Film and Fragmentation	50
2.2.3	The Motion of the Parts	54
2.2.4	Affordances	59
3	The Forms of the Parts of a Building Structure	63
3.1	The Distinction of Subsystems	63
3.2	The Classification of the Parts of Building Structural Subsystems	67
3.3	The Interrelationship of Scheme, Component, and Element	77
3.4	Systematic Aspects of Components and Elements	96
3.4.1	The Phenomenon of Component Nesting	96
3.4.2	The Changing Natures of Building Elements	104
3.5	Three Jointing Strategies	112
4	Hypertext Specifications Format	129
4.1	The Specifications Document	129
4.1.1	Alternate Specifications System Objectives	137
4.2	The Proposed System	139

4.2.1	Computer and Hypercard	139
4.2.2	Diagrammatic Format	148
4.2.3	Uses of the System	166
5	Conclusion: <i>A View to the Whole</i>	183
A	CSI Masterformat List of Section Titles and Numbers	193
B	Example of a Conventional Specifications Section	199
C	Hypercard Card Illustrations	203
D	Hypercard Scripts	213
D.1	ClickText Script	213
D.2	CSI Search Script	214
D.3	CSI Sort Script	215
D.4	Go To Cards Script	222
D.5	Parts List Script	223
D.6	Subsystem List Script	228
D.7	Standards List Script	232

List of Figures

1-1	The tenets of classical architecture include rules for the spatial “ordering” of parts	23
1-2	The whole of a truss is greater than the sum of its parts	24
2-1	Ambient light and the main boundaries of the stationary optic array. The lines in this diagram represent boundaries of visual solid angles, not rays of light (from Edward Reed’s <i>James J. Gibson and the Psychology of Perception</i>)	36
2-2	The principles of linear perspective illustrating the concept of the intersection at the picture plane of visual rays taken between the eye of the viewer and the critical defining boundaries of the object being viewed (from Edward Reed’s <i>James J. Gibson and the Psychology of Perception</i>)	37
2-3	A subjective triangle, whiter than white, appears to have a distinct boarder. Upon closer examination, however, these contours have no physical reality (from Gaetano Kanizsa’s <i>Subjective Contours</i>)	40
2-4	Geometric regularity is not a necessary condition for the formation of subjective surfaces and contours. Amorphous shapes are possible and irregular figures can generate contours (from Gaetano Kanizsa’s <i>Subjective Contours</i>)	41

2-5	Optical illusions show that subjective contours have the same functional effect as real contours. On the left (known as the “Ponzo illustration”) both vertical lines are the same length although the effect of the subjective triangle is to make the line on the left appear longer. The subjective surface in the figure on the right (known as the “Poggen-dorf illusion”) gives rise to an apparent displacement of the slanted line (from Gaetano Kanizsa’s <i>Subjective Contours</i>)	42
2-6	Figures with open borders (as at left) appear to be incomplete. In order to complete the figures the visual system superimposes an opaque surface that fills in the gaps in the figures. If the borders of the figures are closed (as at right) there is no further need for completion and the virtual contours disappear (from Gaetano Kanizsa’s <i>Subjective Contours</i>)	43
2-7	The Villa Stein at Garches (from Colin Rowe’s <i>Transparency: Literal and Phenomenal</i>)	46
2-8	The axonometric view highlights the apparent organizational geometry of the Villa Stein as seen in volumetric form (from Colin Rowe’s <i>Transparency: Literal and Phenomenal</i>)	47
2-9	The internal plan organization of the Villa Stein contradicts that of its initial visual perception from without (from Colin Rowe’s <i>Transparency: Literal and Phenomenal</i>)	47
2-10	Axonometric view of the Palace of the League of Nations (from Colin Rowe’s <i>Transparency: Literal and Phenomenal</i>)	48
2-11	Superimposed over a plan of the Palace of the League of Nations are shown indicators of the perceptually apparent shifting planes of the building’s masses (from Colin Rowe’s <i>Transparency: Literal and Phenomenal</i>)	49
3-1	Examples of building structural schemes: vault and dome, fabric covered tent, simple braced frame	68

3-2	Building structures consisting of more than one structural scheme put together	69
3-3	Examples of <i>shell</i> schemes (top), <i>box</i> schemes (middle), and <i>frame</i> schemes (bottom)	70
3-4	A frame scheme with light cladding panels inserted into it	71
3-5	A frame scheme with box units inserted into it	72
3-6	Building structural scheme “hybrids:” <i>shell and frame</i> at left, <i>panel and frame</i> in the middle, and <i>panel and shell</i> at right	72
3-7	Examples of traditional building elements	73
3-8	<i>Industrialized</i> building elements	74
3-9	Some typical building structural components	76
3-10	Graphic of industrialized “parts”and their combination in buildings (from Richard Bender’s <i>A Crack in the Rear View Mirror</i>)	78
3-11	A frame scheme is like a box scheme with large punched openings	79
3-12	The structural transformation of a shell scheme into a box scheme into a frame scheme	80
3-13	Three methods of stiffening rectilinear frame structural schemes, all of which involve the engagement of element members additional to those of the frame itself: (from left to right) diagonal bracing, solid shear wall, structural cladding –so braced to engage in diaphragm action	83
3-14	The effective resistance of bending forces requires an appropriate adjustment of member material disposition	85
3-15	Two divergent attitudes taken toward the disposition of building structural elements and components within a structural scheme	87
3-16	A rowhouse in Boston’s Back Bay	88
3-17	Exploded view of the major components of the Back Bay rowhouse	89
3-18	Cutaway view of the rowhouse as a box scheme with its elements and components	90
3-19	Vertical wall failure by means of buckling (left) and lateral force (right)	91

3-20	Concentrated loads applied at the top of a brick wall are distributed throughout its network of mortar joints in a triangular pattern at about 45°	92
3-21	Walls parallel to applied lateral forces act as shear planes while effective bracing of the “thin” masonry party walls is provided by the floor plates which act as horizontal diaphragms	93
3-22	Elements of a floor component	94
3-23	The lintel <i>within</i> the wall poses a potential ambiguity between what are elements and what are components	97
3-24	The level 2 component facade as a field in which are nested items from lower component levels	99
3-25	Level 3 and 4 components of the rowhouse facade	99
3-26	Elements of a (custom made) window component	100
3-27	A change in component scale often involves a change in its nested <i>level</i>	101
3-28	The interpretation of <i>additive</i> versus <i>subtractive</i> , nested component articulation	103
3-29	The highly specific natures of steel wide flange sections and “concrete masonry units” render them “generic” and somewhat anonymous in typical industrialized applications while the simple wood timber or stone block are traditionally transformed into artifacts of great specificity	105
3-30	Viollet-le-Duc determined that the Medieval masons optimized the geometry of their structural schemes in order to optimize their size and stability. Shown are two analyses of the critical geometry of the pointed arch and its buttressing. (from Viollet-le-Duc’s <i>Dictionnaire Raisonné</i>)	106
3-31	A traditional masonry wall (top left) as the precursor to a progressive process of element <i>micro-optimization</i>	109
3-32	The formal makeup of a steel wideflange beam	110
3-33	A progression from a solid wood joist (at left) to a lightweight, open-web steel joist (at right)	111

3-34	<i>Monolithic</i> structure is exemplified by its characteristically rigid member connections	113
3-35	<i>Articulated</i> structure is exemplified by pinned connections between members	114
3-36	<i>Mediated</i> structure uses third party, “translational” pieces to adequately bind otherwise separated members together	114
3-37	Examples of <i>monolithic</i> joints	116
3-38	Examples of <i>articulated</i> joints	118
3-39	The controlling effect of the modular unit on the form of an individual part and its placement relative to the grid of a larger assembly (from Schmid and Testa’s <i>Systems Building</i>)	119
3-40	Difficulties arising out of a strict, mechanical integration of standard, modularized parts and the regular grid originate in the turning of corners and at the crossings of orthogonal grid centerlines	121
3-41	Variations in column and wall placement ranging from (1) the strict adherence of material centerlines to grid intersections, (2) material placement within the Tartan grid, and (3) a separation of structural and non-structural members affording the freedom of placement of one while the other remains fixed (from Schmid and Testa’s <i>Systems Building</i>)	121
3-42	Installation tolerances insure that the parts being fitted will not conflict with those already in place (from Schmid and Testa’s <i>Systems Building</i>)	122
3-43	The primacy of the tight fitting joint in monolithic joinery requires that overall dimensions between connections be somewhat flexible (left image) whereas the primacy of the grid/material centerline correspondence in articulated joinery means that the special characteristics of the joint itself (especially in terms of its tolerances) must be flexible (right image).	123
3-44	examples of <i>mediated</i> joints	124

3-45	The “Unistrut” frame system developed in the 1950’s at the University of Michigan makes full use of elaborate connector pieces which “mediate” between basic chord elements	125
3-46	The rich patterning of spanning parts and connectors creates an effect of montage seen in the traditional Arabic screening device, the <i>mushrebeya</i>	126
3-47	A more three-dimensional effect of montage can be seen in the prolific use of mediator joints in some of the work of British architect, Norman Foster (Renault Distribution Centre, Swindon, England, from Norman Foster’s <i>Foster Associates: Buildings and Projects, Vol. II</i>)	126
3-48	Mediated structure allows for both the precise placement of connected members <i>and</i> their “tight” spatial and structural configuration	128
4-1	Outline of the major article headings within a conventional specification section	132
4-2	Outline of the paragraph format in conventional construction specifications (from Harold Rosen’s <i>Construction Specifications Writing</i>) . .	133
4-3	A linear structuring of information common to paper-based text media	141
4-4	A structure of information organized as a web of interconnected nodes and links	145
4-5	An hierarchical organization of information links and nodes	145
4-6	The basic elements of Hypercard (from Danny Goodman’s <i>The Complete Hypercard 2.0 Handbook</i>)	148
4-7	Building system structure in its most abstract form	149
4-8	Building system structure which utilizes an independent <i>envelope</i> schematic subsystem	150
4-9	The <i>foundation</i> subsystem of a building	150
4-10	The <i>superstructure</i> subsystem of a building	151
4-11	The <i>partition</i> subsystem of a building	152
4-12	The <i>services</i> subsystem of a building	152

4-13	Selected branches from the “tree” hierarchy of an example hypercard specification	154
4-14	A multistory, urban, residential building as a test case for the hypertext specifications system	155
4-15	The rowhouse’s <i>superstructure</i>	156
4-16	The <i>wallshell</i> level 1 component of the contemporary rowhouse	157
4-17	The level 2 component, <i>facade</i> of the rowhouse	160
4-18	The rowhouse’s front <i>bay</i> projection, a level 3 component	161
4-19	The level 4 <i>cornice</i> of the rowhouse	162
4-20	The <i>concrete reinforcement</i> element of the rowhouse structure	162
4-21	The level 4 component <i>bond beam</i> shown within the context of its application in the contemporary rowhouse at the junction of the sidewall and the metal floor framing	165
4-22	The level 2 component, <i>sidewall</i> , of the rowhouse structure	165
4-23	The craning into place of a large scale building element which is at once a structural scheme (from Richard Bender’s <i>A Crack in the Rear View Mirror</i>)	176
C-1	Building system Home card	204
C-2	Superstructure card	204
C-3	Wallshell card	205
C-4	Facade card	205
C-5	Bay card	206
C-6	Cornice card	206
C-7	Concrete reinforcement card	207
C-8	ASTM A615 card	207
C-9	Bond beam card	208
C-10	Sidewall card	208
C-11	CSI sorting card	209
C-12	Parts listing card	209

C-13 Parts listing card shown for a conventional, site-built house	210
C-14 Parts listing card shown for a house made from a kit of stock, prefabricated panels	210
C-15 Subsystem listing card	211
C-16 Standards listing card	211

Chapter 1

Introduction: What a Building System is and What it has to do With Construction Specifications

What is a Building System?

System is a word with a two-part definition. It is: a group of parts behaving in some way as to make a unified whole. Is a system the *parts* or is it the *behavior*? It is both, but neither taken singly. A system is not a group of parts but a group of parts *engaged in* a certain kind of behavior. A system is not a certain behavior but the behavior *of* a group of parts. What characterizes the behavior of a group of parts is the result of the system: a *unified whole*. In other words a system is a group of parts behaving in some *holistic* manner, resulting in their unification. Christopher Alexander has said that “the word *system* refers to a particular holistic view of a single thing.”¹

Holistic behavior is the result of the combined behaviors of the parts of a system. Three characteristic aspects of the behavior of the parts are given by Alexander:²

1. Acting together they are stronger than the sum of each individually. For ex-

¹[2]
²[2]

ample, the strength of a rope is greater than that of each of its strands added up.

2. When one part changes, the other parts change also. For example, in a natural ecology, a change in topsoil can have far reaching effects on the vegetation, animal life, topography, air quality and even climate around it.
3. The stabilization of the whole system is shared by all of its parts. The entire work of the system does not depend on any single part exclusively. For example, a candle flame reaches equilibrium because of a balance between oxygen, fuel, and heat. Not any one of these alone.

Further, Alexander points out that in order to speak of something as a system we must be able to state clearly:³

1. the holistic behavior we are focusing on;
2. the *parts* within the thing and the interactions among these parts which cause the holistic behavior defined;
3. the way in which this interaction among parts *causes* the holistic behavior defined.

A system is a phenomenon that is as concerned with the interactions among its parts as it is with the parts themselves.

We must not use the word “system,” then to refer to an object. A system is an abstraction. It is not a special kind of thing, but a special way of looking at a thing. It is a way of focusing attention on some particular holistic behavior in a thing which can only be understood as a product of interaction among parts.⁴

Anything could potentially be called a system. One need only approach it in a certain way, from a certain point of view.

³[2]

⁴[2]

The word *system* has been used in a number of narrower meanings in the building design and construction industry. Often *system* is used as synonymous with *method* or *process* alone. In this case when people speak of a certain “system of construction” they probably mean a “method of construction” or the means of organizing a construction process, its administration. It is likewise popular to call some specialized part of a building or the products of a particular manufacturer a *system*. Thus, when we talk about a *heating system* we are often referring to a type of heating equipment or perhaps the furnace of a specific manufacturer. Similarly, a *building system* can be a *kit-of-parts* which, when assembled, makes a building or part of a building. The use of the word *system* here often refers to the availability of groups of parts in pre-coordinated, pre-packaged units that can be purchased off-the-shelf for immediate assembly on site.

In the examples given above, the word *system* is synonymous with either a collection of objects (as in the latter examples) or with some aspect of process, administration, means or methods (as in the first example). But none of them satisfies the full criteria of the two-part definition with which this chapter began. These narrower definitions reveal their own incompatibility with the first definition given and, in so doing, their inapplicability to the subject of this paper. While it is not my intention to show that pre-engineered or pre-packaged products *cannot* participate in systems activities, the systems concept in its broadest sense implies much more than does the term as it is commonly applied to parts or processes per se.

If a *system* is a group of parts exhibiting some holistic behavior toward a unified whole, then a *building system* is simply the parts of a building exhibiting some holistic behavior toward a unified whole, i.e., the building. Not only in the parts themselves is such holistic behavior manifest, but more importantly, in their specific interaction within the whole: the interrelations of the parts.

Parts, Wholes, and Sums

The two main components of any system are the parts and the whole. These may be the material parts and the material whole but they may also be the behavioral

or relational parts of a system and its resulting, holistic *effect*. To regard the *whole* as an object is to “refer to something with a spatial extension,”⁵ that is, a distinct material corporeality. If this is the case, then the parts also are spatial entities which are subsets of the whole. Used in terms of a functional effect or behavior, the word *whole* refers to a property or process of some kind in which case it may constitute “a pattern of relations between certain specified kinds of objects or events.”⁶ Its parts, then, are the individual relations which when combined create the overall pattern.

The definition of *whole* most useful for the understanding of a building is that given by Ernest Nagel, which refers to “any system whose spatial parts stand to each other in various relations of dynamical dependence.”⁷ This definition inextricably links the words *whole* and *system* and, like the definition of *system*, necessarily involves two aspects, both the *parts* and their *dynamical dependence*.

The familiar phrase, “the whole is greater than the sum of its parts,” implies a particular kind of relationship between *part* and *whole* that really depends on the specific meaning of the word *sum*. Like *system*, the word *sum* can be used in many ways. Cases when a whole *is* equal to the sum of its parts can be found in the realm of mathematics where, for example, the addition of two real numbers yields nothing more than their sum. Other uses of the term *sum* drive more specifically at the order of the resultant whole, the regularity of its pattern of configuration. An ordered sum is usually seen in terms of a spatial or temporal relationship between its parts.⁸

Applied to architectural examples the first use of the word *sum* can be helpful in estimating material quantities and equating a building’s total cost to the sum of the costs of each of its parts and the labor required for their installation. In the second, or *ordered* sense of *sum*, it can be said, for example, that the composition of a classical Greek facade relies on the sum of various classical elements, scaled and disposed in certain canonical spatial relationships to each other (see figure 1-1). In this *ordered* relationship the whole is greater than the sum of its parts, albeit trivially so since the

⁵[18, p. 136]

⁶[18, p. 137]

⁷[18, p. 138]

⁸[18, p. 143]

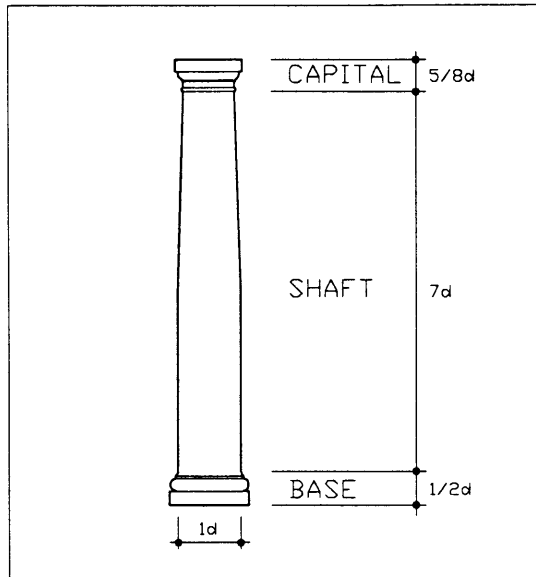


Figure 1-1: The tenets of classical architecture include rules for the spatial “ordering” of parts

composition of a facade is but one aspect of the building as a system and, arguably, not the most important one at that.

There is another sense of the word *sum*, however, which accounts for more than the simple addition and spatial ordering of the parts of a whole. This is the sense that takes into consideration the “dynamical dependence” of the parts relative to the whole. The truss is an example from the field of structural engineering which displays such interdependent behavior amongst its parts (see figure 1-2). Its parts are simple, stick-like members (called chords) which jointly strengthen and stabilize the truss, sharing its loads respectively in either tension or compression. Here a mutual reliance of the parts produces a whole whose effective behavior is clearly predicated on the individual roles of the parts and yet is completely unique. The net affordance of the truss, its ability to support loads in spanning open space, implies a global bending action, yet inherent in its geometry and member connections is the complete avoidance of internal bending moment. The chords are engaged according to their own most efficient structural capabilities: the resistance of pure tension and compression.

The effect of the truss is a result not of the simple compilation of additive parts,

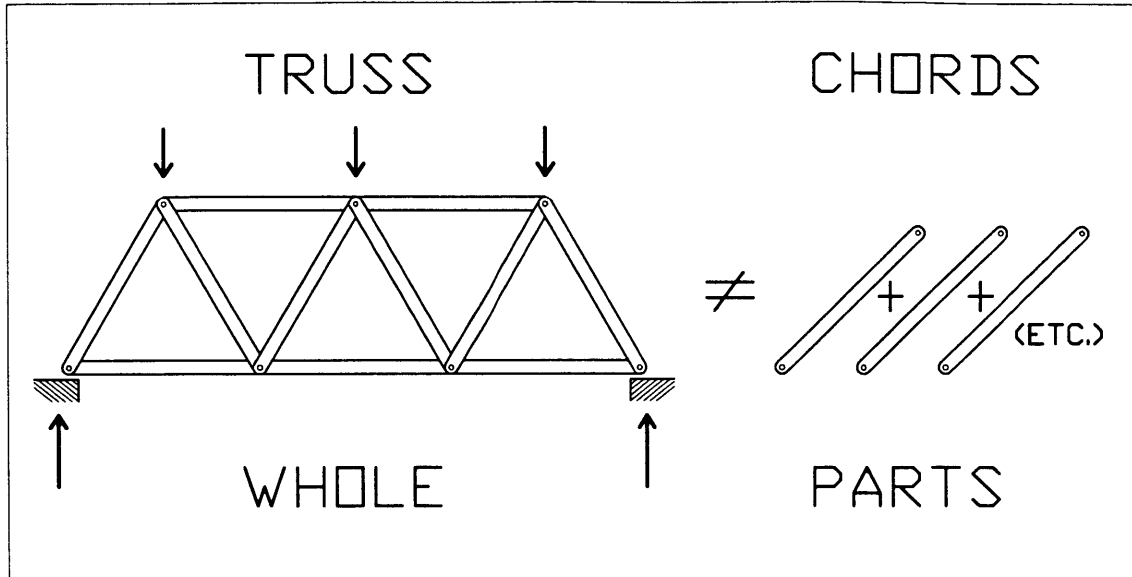


Figure 1-2: The whole of a truss is greater than the sum of its parts

nor is it a product of the order of their spatial composition alone. Rather, the holistic action of the truss is a result of the interactive behavior of its individual parts with respect to the whole. In this sense the truss is profoundly more than the sum of its parts. It is, viewed in this way, a *system*.

Another word to describe a whole which is truly greater than the sum of its parts is *organic*. Consistent with our general definition of a system, something which is organic embodies the purposeful, interdependent behavior of a group of parts toward some collective and unified effect. Furthermore, the process of interdependent behavior between parts in an organic system changes them from individual entities, with individual properties of behavior, to a collective body exhibiting a unique and purposeful behavior. Nagel explains the phenomenon thus:

Organic or “functional” wholes have been defined as systems “the behavior of which is not determined by that of their individual elements, but where the part-processes are themselves determined by the intrinsic nature of the whole.” What is distinctive of such systems, therefore is that their parts do not act, and do not possess characteristics, *independently* of one another. On the contrary, their parts are supposed to be so related that any alternation in one of them causes changes in *all* of the other parts. In

consequence, functional wholes are also said to be systems which cannot be built up out of elements by combining these latter *seriatim* without producing changes in all those elements. Moreover, such wholes cannot have any part removed, without altering both that part and the remaining parts of the system. Accordingly, it is often claimed that a functional whole cannot be properly analyzed from an “additive point of view;” that is, the characteristic modes of functioning of its constituents must be studied *in situ*, and the structure of activities of the whole cannot be inferred from the properties displayed by its constituents in isolation from the whole.⁹

Implied in Nagel’s description are all of the conditions given by Alexander of holistic behavior characteristic of systems: the strength of the whole is not equal to that of its parts taken singly; a change in one part produces changes in all the others; and the stabilization of the whole is shared among all of the parts. These are also all characteristics that we ascribe to good design in buildings. To say that a building is *organic* does not necessarily mean that it is curvilinear or that it melds itself into the earth. Rather, it is to say that a building effectively integrates its several parts according to their best individual abilities toward a whole which performs well (as a building). Organic behavior in a building is nothing short of efficient, holistic behavior.

Morphology and Models

We have established in a most general way that the distinction of a *systematic* or *organic* whole depends on the relationships of its parts. How do we come to recognize and interpret these relationships? Common sense and experience tell us that we observe relationships between things through first-hand experience of the world around us. In fact, our interaction with the world can be seen as its own kind of system since it involves not only ourselves and material objects but also a way of “looking at” (or

⁹[18, p. 147]

understanding) the relationships between us. Chapter 2 is concerned with the mutual relationships between the observer and environment in human perceptual experience.

Having only our sense perception to distinguish the systems phenomenon in buildings initially, there are means of analysis by which we can pinpoint the essential concepts of systems in architecture. We can characterize the parts based on what we have seen, the phenomena we have observed. We can also generalize the roles of the parts, stereotyping them toward a simplified classification. By examining the hierarchical breakdown of parts into categories, we can begin to focus attention on the way they work together, i.e., their interrelationships.

We are capable of discerning interrelationships among the things around us that are apparently independent of our noticing them or not. We can safely assume, for example, that the truss phenomenon depicted in figure 1-2 and seen in bridges, buildings, and towers everywhere, is equally valid regardless of our recognition of it at any particular time. On the other hand, we have become familiar with the behavior of trusses only through concerted investigations into their qualities and characteristics, into what they can and cannot do. In paying attention to something in this manner we are endeavoring to determine *what* it is and *how* it is so. Understanding the system associated with something we perceive involves some recognition of the intimate relationship between its existence, its physical aspects (like shape, size, and density), and its effective behavior, i.e., how it reacts with other things. The sum of these qualities constitutes its *form*. The forms of the parts of a building system is the overarching concern of chapter 3.

To inquire into what something *is* is to inquire into its *form*.¹⁰ By *form* I do not mean the shape or “external physical aspect” of a thing exclusively. Rather, in the broader, Scholastic sense of the word, I mean form to be the characteristics that make a thing what it is, that give it its definition. Thomas Aquinas defined form as “the essential quality or determining principle of every individual thing.”¹¹ The *form* of something, then, is all of the qualities that make the thing what it is. It is

¹⁰*form* comes from the Latin *forma* roughly equivalent to the Greek word *morph*, from which we get the word *morphology*.

¹¹[28, p. 24]

its *essence*.

The form of a building involves not just its shape, but also how it works and why it is the way it is. In an investigation of a building's form, we can look variously at its behavior under loads, according to the principles of statics, and we can also look at its outward appearance or geometry, also known as its *physiognomy*. Only in concept are these aspects of form independent of one another. In real, material things (those that we perceive directly) shape and behavior are intimately related and integral. They are inherent in the building object as important aspects of its essence.

Through experience we come to know the forms of the parts of buildings. We “read” the parts, trying to translate their form through various means of abstraction. Reflecting on what we have originally perceived, we can modify and improve our understanding of the essence of something, leading to a more discriminating taxonomy of its parts. In a building we may thus determine what are walls, what are floors, what are doors, etc. and then delve even further into the makeup of each of these parts toward an understanding of their own internal structure to see how it relates back to the structure of the larger, whole building.

Models of buildings are sometimes made to try to encapsulate certain aspects of their form on which we want to focus attention. Drawings and sketches are done for the same reason. They are representations of form, abstractions of some particular characteristic of a building that we find important to record and communicate. Even in speaking about a building we are selectively representing something of its essence in order to make a point.

Our understanding of “representation” originates in the seemingly deep-seated presupposition that although physical objects are sense perceived things, particular to a place and time and thus subservient to the laws of physical nature, *ideas* about things (their pure characteristics and qualities, both material and immaterial) are stuff for the mind alone. In short, we believe that all material bodies are possessed of both a tangible component and an intangible component. The idea of something is its intangible component.¹²

¹²As based on Aristotle's “hylomorphic theory,” for example. [1]

The tangible component of a particular object, its having a material embodiment, cannot exist devoid of its having any characteristic whatever. One cannot conceive of matter without form. But everyone knows that ideas are not constrained to material things since one can easily conceive of (or envision) a unicorn, for example without there being an actual unicorn present to direct physical perception. The form of an object, without the constraints of any immediate material manifestation, is universal in that it is infinitely reproducible and changeable (or transformable). But for its characteristics (things about it) to be understood by those who have never actually experienced one first-hand, they must be communicated from one human mind to another. Effective communication depends on the legibility (or the clarity) of representation.

For an intangible idea to be shared between people it must take on, temporarily, the guise of something tangible, while in the abstract representation (especially in the media of speech, writing, and pictures) of material bodies we strive for something more efficiently handled than the original which it describes. Hence it is easier to *talk about* a bridge than it is to pass one around for others to see, and it is easier to *draw* a picture of an army than it is to assemble one at hand purely for the sake of demonstrating a point.

Such common sense is difficult to dispute but perhaps the more poignant question *vis-à-vis* architecture is: what makes an abstract representation of a material object effective? In other words, by what criteria do we determine that my drawing (or other description) of an army is better than yours?

The answer relies again on our understanding of form as the conglomeration of all the qualities on a thing – in short, its *essence*. The more qualities of the thing that a representation of it possesses, the better representation it is. Creation of an accurate representation, then, depends on the degree to which the abstraction and the original thing which it represents share a common form. A good rendering of a building is recognized as such by everyone precisely because the building that was drawn and the drawing itself share important elements of the same recognizable form – namely a visual likeness. The drawing and the building in this respect are *isomorphic* (*iso*

= same, *morph* = form). In general, a representation of the form of something is an effective projection of the nature of its reality within an orderly structure of ideals.

Hypertext and the Representation of Systems

If the object of representation is to capture something of the form of the thing being represented—an essential quality or idea that makes it what it is—and if a system refers to a way of looking at some holistic entity as a collection of parts with respect to their interrelationships, especially the essential qualities of their interaction, then a highly effective representation of the form of a thing is a representation that illuminates its system.

In the design process, an awareness of the systems characteristics of the building can be reflected in the development of both the drawings and the specifications. The process of formalizing these characteristics in the media of graphic and verbal design representation will foster a coherence to the whole building that will carry through, in its contract documentation, to its built realization. Architects use both pictures and words for this purpose.

Drawings are useful for producing visual likenesses as representations of form. They can efficiently record the spatial and geometric relationships between the parts of a building. Non-spatial relationships, like the performance or behavior of parts over time – their “dynamical dependence” – however, are best described through words.

Traditionally, architects have maintained a distinct separation between spatial information about a building, manifest in architectural drawings, and verbal description of its characteristics, in written construction specifications. The conventional format of drawings is large sheets of paper onto which are arranged various geometrical images of the layout of the building. The conventional format of specifications is that of a book, divided into chapters that each deal with a specific aspect of how the building is to be made and how it must perform in use.

It is difficult to communicate systems characteristics like the behavior of mutually interactive parts in architectural drawings except by notating them with words, a

method that is frequently practiced. But writing is unique in that it involves a very carefully worked-out “system” of its own, a system of visual symbols that, when combined in certain ways, represent verbal utterances set down in material form (usually ink on paper). Since writing combines aspects of both verbal communication and visual/spatial composition (of word-symbols arranged on paper, for example), it is possible to manipulate in writing not only verbal narration but also the idea of spatial continuity and connectivity of groups of text representing the *parts* of its overall content or meaning. A construction specifications document can, for example, convey both spatial and non-spatial information about a building through the relationship between the meaning of its words and its format, the way the words are visually presented to the reader.

Recent advancements in computer technology have opened up new possibilities for the alignment of the media or format of the recording and presentation of information, with the form of the larger object to which the information refers. In the case of architectural contract documents (the drawings and the specifications), the “object” is the whole building as an overarching system that both governs and is created by the contributions of its many constituent parts. In the electronic medium of the computer, a great deal of flexibility in the association and linking of parts of information (information about parts) with respect to the whole document (the whole building) is enjoyed.

The object of the construction specifications format developed in this thesis is to strengthen the relationship between the textual representation of building form in a specifications document and the form of the actual building being represented. This involves the use of a computer documentation format which is generally isomorphic to the buildings (building systems) to which it is applied. A specifications documentation format utilizing a hypertext software is proposed in chapter 4. In the development of the specifications format, these features will be further explained and elaborated upon.

Although we may be unable to, nor have any practical need to, pinpoint and document *every* aspect of a building that is related to its systematic behavior, the

conscientious modeling of what we see as the most critical aspects of a building system, the specific interrelations of its parts, can bring us closer to an understanding of the *object* of a building – *what it actually is*.

Chapter 2

The Observer and the Environment

2.1 Visual Perception Theory

Builders know that buildings are formed by the manipulation and assemblage of material objects in space according to their shapes, weights, and physical capabilities. This simple concept is a useful basis for talking about the objects of building construction as objects of visual perception. Visual perception is not the exclusive means by which we come to know the things of the world. Certainly hearing and touch and scent contribute to our overall sense of location. Sight, however, has a significant impact on the “legibility” of architecture – its detailed clarity to the human observer from multiple vantage points. Psychologist James J. Gibson explained visual perception as the acquiring of information about things directly through visual interaction with them. His work addresses the practical problems of everyday perception in the world: the problems of locomotion, object identification, and manipulation. Not surprisingly, these are also the problems of building design, construction, and use.

Gibson’s explanation of visual perception involves not simply a retinal image which is processed by an “eye within the brain.” Rather, he describes a more holistic scenario in which “natural vision depends on the eyes in the head on a body supported by

the ground, the brain being only the central organ of a complete visual system.”¹ An “ecological approach to visual perception,” as he appropriately termed his theory, considers the broader context of perception as a system by which visual information is communicated.

Our perceptual environment is our surroundings and this environment is comprised of the things we can sense: things possessed of physical and temporal dimensions within the perceptual limitations of the human body. Gibson’s concepts provide a model for understanding the perception of the objects of building construction, as the “parts” of architecture. Practical limitations on the scope of our perceptual abilities are of the essence of Gibson’s approach to the environment. This investigation concerns those parts of buildings which are measured in feet and inches. They are relatively anthropometric in comparison with the infinitesimally small and large subjects of the physicist and the astronomer which do not fall within the range of our natural perceptual abilities.

An observer’s direct perception of her immediate field of vision encompasses what are, figuratively, the “objects at hand.” This field of vision is known as the *ambient optic array* – the geometrical visual layout in light that surrounds the observer. It is a structuring of the ambient light available at the point of observation – a panorama about the observer suggesting the dynamic nature of perception due to *ambient vision* and *ambulatory vision*.² Ambient vision is that attained by the movement of the observer’s head, side to side, up and down, etc. Ambulatory vision is that gained through the locomotion of the observer, walking, running, riding, etc. The optic array is thus perceived as a moving and changing field of view, a changing composition of illuminated surfaces.

The spatial medium (or “gaseous atmosphere”) of the ambient optic array – the space between the observer and the surfaces – Gibson refers to as the *environmental medium*. The solid, material objects whose surfaces we perceive he calls *environmental substances*. *Surface* is the interface of environmental media and substantial media. It

¹[10, p. 1]

²[10, p. 1]

is inextricably bound to the two basic entities, substance and environment (or space), and yet it can be described by its own unique characteristics. These are listed by Gibson:³

1. All persisting substances have surfaces and all surfaces have a layout.
2. Any surface has resistance to deformation, depending on the *viscosity* of the substance.
3. Any surface has resistance to disintegration, depending on the *cohesion* of the substance.
4. Any surface has a characteristic texture, depending on the *composition* of the substance. It generally has both a layout texture and a pigment texture.
5. Any surface has a characteristic shape, or large-scale layout.
6. A surface may be strongly or weakly illuminated, in light or in shade.
7. An illuminated surface may absorb either much or little of the illumination falling on it.
8. A surface has a characteristic reflectance, depending on the substance.
9. A surface has a characteristic distribution of the reflectance ratios of the different wavelengths of the light, depending on the substance. This property is what I will call its color, in the sense that the different distributions constitute different colors.

Implicit in these characteristics is Gibson's position that surfaces are necessarily associated with real, tactile objects, and not the mass-less abstractions of Euclidean geometry which, being theoretical, are not bound to the reality of the senses.⁴ Gibson rightly points out that, at least from a perceptual standpoint, only three dimensional things exist in the sensed world.⁵ While the visual array that we see is a matter of

³[10, pp. 23-24]

⁴[10, pp. 35-6] To his contrast of abstract, Euclidean geometry and material, formal geometry, Gibson compares the distinction between the terms "plane" and "surface" respectively.

⁵[10, p. 33]

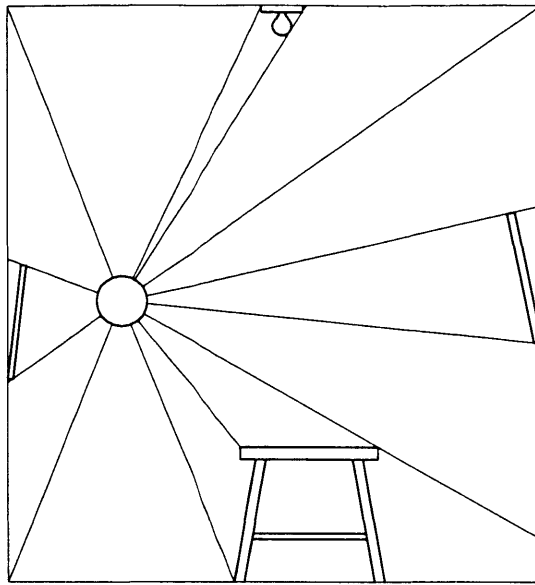


Figure 2-1: Ambient light and the main boundaries of the stationary optic array. The lines in this diagram represent boundaries of visual solid angles, not rays of light (from Edward Reed's *James J. Gibson and the Psychology of Perception*)

surface composition and not volumetric form *per se*, knowledge of objects' relative positions and three-dimensional composition is gleaned from the information the surfaces of the visual array provide. Gibson believed that, as far as the strictly visual activity of perception is concerned, all that one "sees" are illuminated surfaces of things and that one's comprehension of their three dimensional existence is a result of the information that is provided by thus perceiving them.

Differentiation of surface forms within the array, then, is primarily accomplished by the variety of light energies that may enter the eye and stimulate the photoreceptors of the retina. The visual structure that is apparent in the array is a result of the contrast between the surfaces that are seen. Silhouettes, or textured shapes of the distinct surfaces of the array are received by the eye along the visual angles (Gibson calls them *solid angles*) whose apexes coincide with the point of observation (the eyes of the observer) and whose opposite chords are the edges or corners of the surfaces (figures 2-1 and 2-2). One's reception and ordering of the visual stimuli received from the optic array comprise the *perceptual system*.⁶ Thus, within the perceptual system

⁶[10, p. 55]

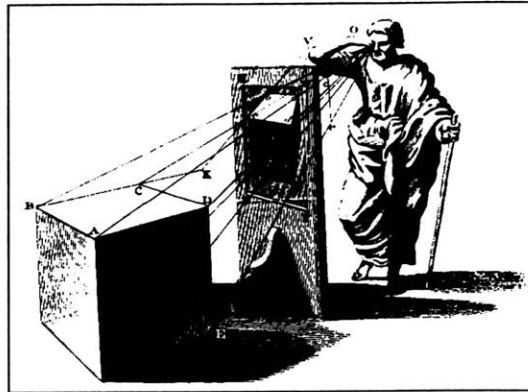


Figure 2-2: The principles of linear perspective illustrating the concept of the intersection at the picture plane of visual rays taken between the eye of the viewer and the critical defining boundaries of the object being viewed (from Edward Reed's *James J. Gibson and the Psychology of Perception*)

the *stimulus energy*, the reception of light from the surfaces of the visual array by the eyes, is seen as clearly distinct from the *stimulus information* which is the observer's interpretation of that stimulus: her "making sense of it." Both are inherent in the visual process.

Things within the optic array are changing. They are changing because the observer is moving about relative to them, creating a shifting or "flowing" perspective. They are also changing due to environmental forces acting on them (they are corrupted by fire, wind, and water, for example). Since the optic array transmits stimuli to the eyes in accordance with their ability to differentiate surfaces within certain physical limits, things can apparently appear and disappear by being at one moment within one's field of vision and at the next moment outside of it. But they can also "come in and out of vision" by virtue of their own change of material state. This is not to say that matter and energy are not conserved at the molecular level but that at the perceptual level, where we are truly constrained by the level of sensitivity of our eyes (we cannot visually perceive the formation of a mountain range in geologic time and we cannot visually perceive the splitting of an atom), things can, in fact, come into existence or cease to exist. Gibson uses the example of a block of ice

melting and evaporating to demonstrate the phenomenon of a substance perceptually ceasing to exist. Indeed, when a material changes state its surfaces do come into or go out of perceptual existence.⁷ Perception of the change of certain elements within the ambient optic array is possible only with respect to the relative stasis of others in their background. The most stable elements that we can see are the surface of the earth and the dome of the sky. They form the context within which all the apparent changes of the optic array occur. This hierarchical layering of surfaces within their larger context Gibson calls *nesting*. Gibson refers to those aspects of the optic array which are relatively persistent over time as *invariant structure* while those which are perceptibly changing he calls *variant*. The appearance of change within the optic array with the movement of the observer he calls *perspective structure*. Invariant structure is measured against the changes of the array's perspective structure. These terms will be elaborated upon later in this chapter.

What has been outlined here is a theory of visual perception called the theory of *direct perception*.⁸ In summary:

Direct perception is the activity of getting information from the ambient array of light.⁹

Conventional theories of vision have attempted to isolate the light-sensitive mechanism of the eye as a kind of camera which projects images into the brain for viewing and comprehension. Consequently, the scientific study of vision has largely been limited to testing the eye's response to momentary, fixed images. This reductionist method is inconsistent with natural vision, where movement and change of the optic array is a continuous experience for the observer.

The ecological approach to visual perception...begins with the flowing array of the observer who walks from one vista to another, moves around an object of interest, and can approach it for scrutiny, thus extracting the

⁷[10, pp. 13-14]

⁸[10]

⁹[10, p. 147]

invariants that underlie the changing perspective structure and seeing the connections between hidden and unhidded surfaces.¹⁰

The experience of architecture, the most fundamental level at which we can understand it, is not a series of still frames or “snap–shots.” It is a continuous unfolding in which not only is our visual array changing but also, concomitantly is our comprehension of what it is we are seeing. Our understanding of the parts of architecture relies on our perception of parts which, though changing, maintain their status as objects to the extent that they can be identified as coherent, individual things. The interpretive nature of this differentiation induces a dialogue or exchange between the observer and the objects of the visual experience. The experience of architecture is dialectic in the sense that its significance lies not wholly within the objects that can be seen (existing to be deciphered like a code), nor within the viewer innately (and somehow projected onto the objects from the mind), but in the interaction of the two. James Gibson’s concept of the direct perception of a flowing visual array affords a productive exploitation of the dialectic between observers and parts of buildings which is a natural basis for the “reading” of architecture. The remainder of this chapter will apply Gibsons accounting of the importance of movement and change in the visual array with a number of other supporting sense perceptual phenomena toward a clearer understanding of the experience of architecture as an interaction between the sense perceptual system and the things that are perceived by it.

2.2 The Dialogue of Visual Experience

To elucidate some aspects of human perception as significant to the discernment of parts in buildings, several well-known optical effects are here described as the products of an interaction between the observer and the visual environment. These are: subjective contours, phenomenal transparency, fragmentation and completion, parallax motion and perspective structure. Lastly, the useful potential, or *affordances* of a building and its parts will be discussed. I have intimated above that the motion

¹⁰[10, p. 303]

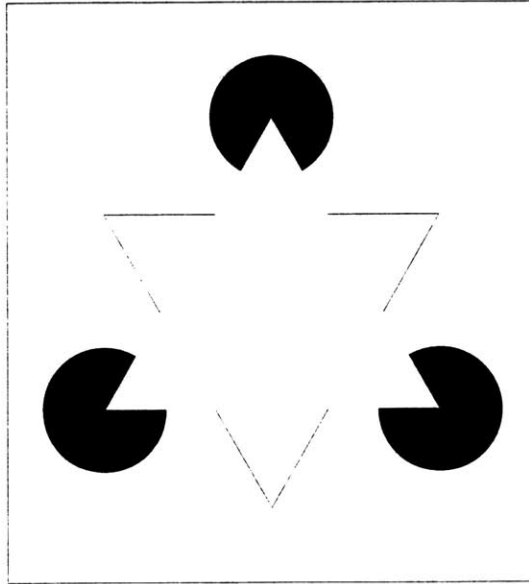


Figure 2-3: A subjective triangle, whiter than white, appears to have a distinct border. Upon closer examination, however, these contours have no physical reality (from Gaetano Kanizsa's *Subjective Contours*)

of the observer through her environment is a crucial factor in the interpretation of parts objects. At the same time locomotion is not the only generator of interaction as is evidenced in many of these visual and spatial phenomena.

2.2.1 Subjective Contours and Phenomenal Transparency

Perception involves a kind of interpretive seeing on the part of the observer. Studied extensively in Gestalt psychology, one aspect of interpretive seeing is the perceptual completion of visual forms according to the viewer's innate preconceptions of their potential formal "goodness." The visual completion of fragmented two-dimensional graphic shapes with virtual lines formulated by the observer, called the phenomenon of *subjective contours* by Gaetano Kanizsa, is a good example of such interpretation.¹¹ In viewing the incomplete printed shapes of figure 2-3, both the connecting lines and the overlapping planar geometries necessary to produce continuous, unbroken lines and simple, regular, overlapping shapes are almost invariably apparent. In the reality of the printed page no such continuity of shapes exists. Their composition does

¹¹[12]

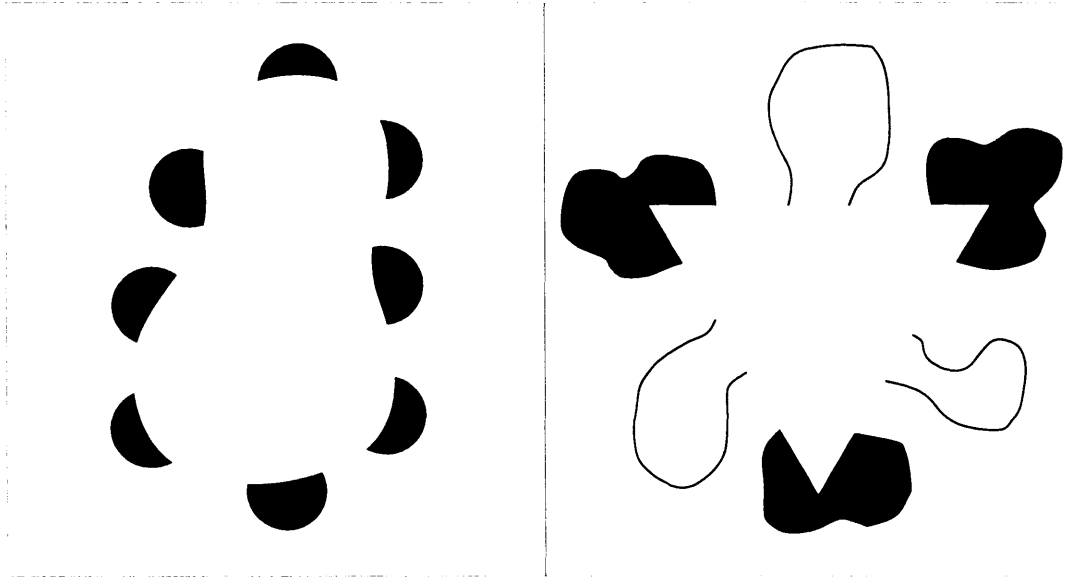


Figure 2-4: Geometric regularity is not a necessary condition for the formation of subjective surfaces and contours. Amorphous shapes are possible and irregular figures can generate contours (from Gaetano Kanizsa's *Subjective Contours*)

suggest that these figures might consist of pieces of black and white paper cut out in regular geometries and laid down overlapping one another. And yet this reading of the pattern is equally the result of the reader's "wanting them to be" completed, and merely visually obscured by their overlap. Our experience of them is interactive in that the interpretation of what they represent is the result of both a suggestion on the part of the object itself (based on its particular physical characteristics) and our own desire for it to be something that is whole. The relationship between the suggestion of the graphic and the selective perception or interpretive seeing on the part of the observer is so pronounced as to make the completion of the printed shapes a phenomenal reality for nearly every observer who encounters them. Even if we know they are not there, we still see the connecting lines and overlapping planes as either concealed or concealing, self contained, opaque layers.

One of the characteristic effects of subjective contours is that the top figure appears brighter than the background beneath it (figure 2-4). Another is that the observer can readily discriminate between the fragments that belong to one complete form and the spurious interfering lines which are perceived as belonging to something else,

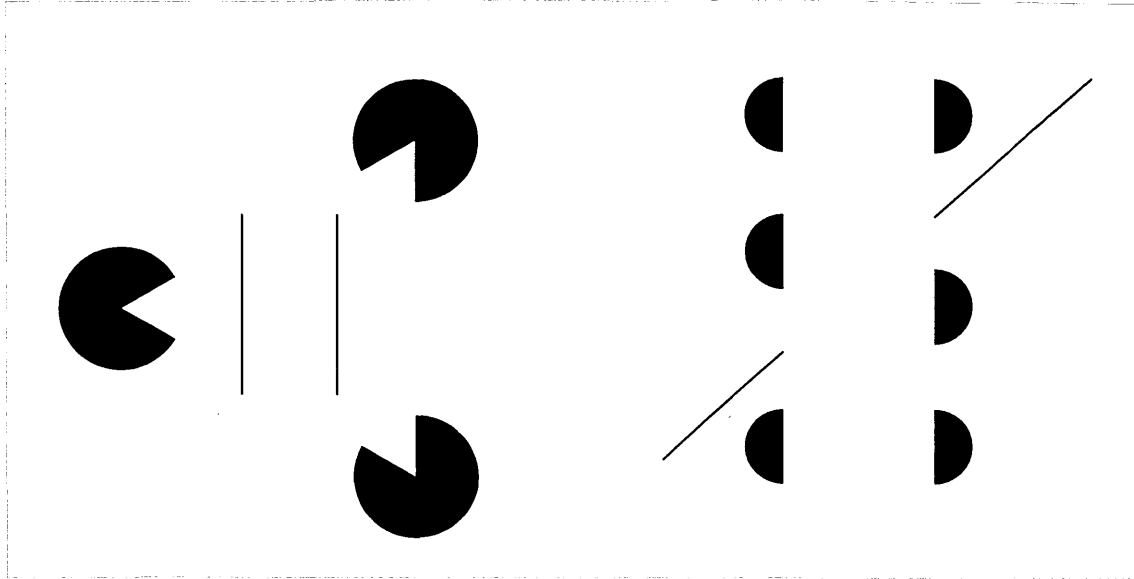


Figure 2-5: Optical illusions show that subjective contours have the same functional effect as real contours. On the left (known as the “Ponzo illustration”) both vertical lines are the same length although the effect of the subjective triangle is to make the line on the left appear longer. The subjective surface in the figure on the right (known as the “Poggendorf illusion”) gives rise to an apparent displacement of the slanted line (from Gaetano Kanizsa’s *Subjective Contours*)

although the juxtaposition of the parts of different forms may be the cause of other optical illusions (figure 2-5).

Kanizsa offers two hypothetical explanations for the subjective contours phenomenon. One is that “the short line segments in the visual stimulus activate some of the contour detectors, and signals from the activated detectors are interpreted as being a stimulus from a continuous line.”¹² This explanation assumes that only lines are seen as virtually continuous and that they always “continue in the same direction as the stimulus line.” Since this theory does not account for the apparent continuity of two-dimensional planes nor non-straight lines (an assumption which is disproved in Kanizsa’s research wherein curvilinear shapes are also shown to create virtual contours –see figure 2-4), it is not considered wholly adequate.

The more plausible explanation Kanizsa gives is that the subjective contours, the visual lines and planes that we see in certain images where none, in fact, exist, are

¹²[12, p. 50]

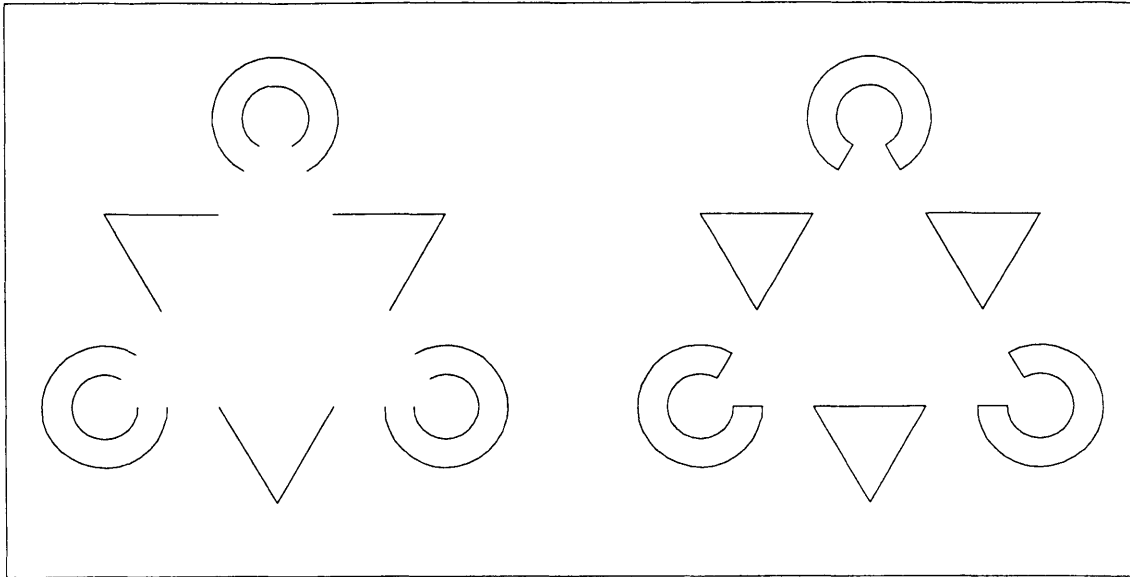


Figure 2-6: Figures with open borders (as at left) appear to be incomplete. In order to complete the figures the visual system superimposes an opaque surface that fills in the gaps in the figures. If the borders of the figures are closed (as at right) there is no further need for completion and the virtual contours disappear (from Gaetano Kanizsa's *Subjective Contours*)

“the result of perceiving a surface and not [lines per se.] The subjective surface in turn is generated by the tendency of the visual system to complete certain figural elements.”¹³ Phenomenal surface perception theory is supported by the disappearance of subjective contours when the open ended geometries of the image are actually completed (figure 2-6).

This view of subjective contours, significantly influenced by Gestalt psychology, can be extended further to account for not only “the tendency of the visual system to complete certain figural elements” but as well our seemingly natural desire to determine the relative depth position of objects, under the presumption that they exist in a three-dimensional visual field. As mobile creatures we have a need to organize space with respect to the objects that we encounter in it. Our concept of organization often involves a sense of layering of the visual environment with successive spatial zones, receding into the distance.

Graphic images which induce a reading of subjective contours can, in this sense, be

¹³[12, p. 52]

regarded as two-dimensional likenesses of the visually overlapping surfaces of solid objects discerned in the environmental optic array— surfaces whose visual composition betrays a nesting of solid objects within an environmental medium. In their illusions of three-dimensional space, subjective contours demonstrate how two-dimensional image can create the compelling effect of volume.¹⁴ But the kind of dialogue fostered in the effects of two-dimensional subjective contours can be recognized in the three-dimensional realm of architecture and environment as well. In the perception of a three-dimensional world, the kind of perceptual ambiguity generated by visual experience of a graphic design is amplified by the interjection of real volume between the observer and constructed material objects. Consistent with both Kanizsa's and Gibson's observations,¹⁵ there is a natural tendency to understand overlapping, object forms in the optic array as composed of continuous parts which are visually fragmented by their partial concealment behind more forward objects. So common are these appearances that they are rarely given a second thought. They might easily, however, be considered as three-dimensional counterparts to the subjective contours of two dimensional imagery studied by Kanizsa.

The visual suggestion of such continuity in architecture specifically has been addressed by Colin Rowe in his essay *Transparency: Literal and Phenomenal*. Rowe calls it *phenomenal transparency*.¹⁶ Literal transparency refers to the material quality whose opposite is opacity. It is the kind of transparency used to describe a plate glass shopfront or the view through an open loggia. Phenomenal transparency, on the other hand, refers to the interpretive effect of a layered space as defined by material surfaces which suggest their own coplanar extension (creating a continuity of visual form strikingly similar to that of subjective contours). The virtual planes created in phenomenal transparency are then not only visually intimated by the objects' arrangements but can often be physically penetrated by the observer as well, viewed from different angles and even touched. Rowe explains the distinction between literal

¹⁴Early twentieth-century Cubist painters capitalized on this, referring to its effects as virtual or phenomenal space. [24]

¹⁵[10]

¹⁶[24]

and phenomenal transparency thus:

Transparency may be an inherent quality of substance – as in a wire mesh or glass curtain wall, or it may be an inherent quality of organization... ¹⁷

Transparency relating to the “organization” of visual objects is *phenomenal transparency* in the same way that the specific organization of the fragmented line segments in Kanizsa’s illusions was responsible for the effects of subjective contours and not any quality inherent in the lines themselves. The organization of the parts here, as in Gibson’s optic array, is of greater importance for the generation of dialogue between the conscious observer and the objects, than are the objects or the observer alone. Such meaning is read by the observer in the relationships between parts *through* her own relationship to them.

Phenomenal transparency, as an architectural effect in Rowe’s description, often involves the visual reading of prismatic parts of architecture as extending continuously though an entire building volume when, upon further investigation they are found to be broken or penetrated by other elements. Rowe’s phenomenal transparency involves relatively large scale building parts (wall and floor slabs, for example) which, in their perceived completion, intersect within the overarching framework of the building whole and thereby strengthen the coherence of its overall sense of formal order. He compares this phenomenal effect with a similar but more literal one in the realm of visual art described by Gyorgy Kepes:

The figures are endowed with transparency: that is, they are able to interpenetrate without an optical destruction of each other. Transparency, however, implies more than an optical characteristic, it implies a broader spatial order.¹⁸

In Rowe’s analysis of Le Corbusier’s Villa Stein at Garches, the overall spatial order implied by the phenomenal transparency of the building’s planar floors and walls is not necessarily indicative of the reality of these elements (figure 2-7). At

¹⁷[24, p. 161]

¹⁸Gyorgy Kepes. *Language of Vision*. Chicago, 1944, p. 77.



Figure 2-7: The Villa Stein at Garches (from Colin Rowe's *Transparency: Literal and Phenomenal*)

Garches

the volume revealed [by the floor plan and internal disposition of spaces] is almost directly opposite to that which might have been anticipated [from the facade].¹⁹

Here the illusion of depth given from one viewing aspect of the building is contradicted by that of another. Figures 2-8 and 2-9 reveal respectively an implication of an east-west slicing of the building in its elevation and a contradictory north-south division of the spaces in plan. Rowe wrote of the Villa Stein:

Thus, throughout this house, there is that contradiction of spatial dimensions which Kepes recognizes as characteristic of transparency. There is a continuous dialectic between fact and implication. The reality of deep space is constantly opposed to the inference of shallow; and, by means of the resultant tension, reading after reading is enforced. The five layers of space which, vertically, divide the building's volume and the four layers of space which cut it horizontally will all, from time to time, claim attention;

¹⁹[24, p. 169]

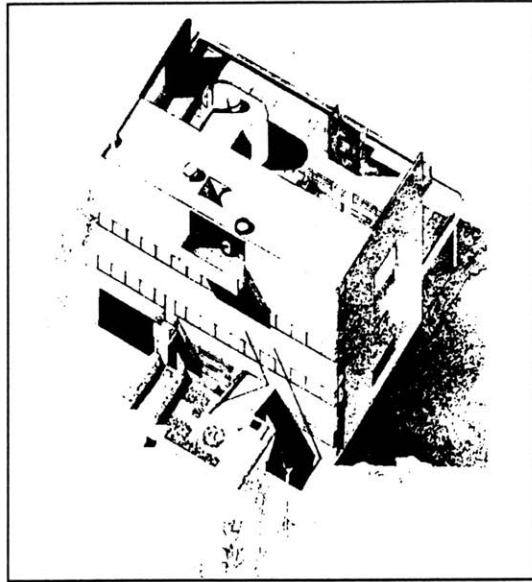


Figure 2-8: The axonometric view highlights the apparent organizational geometry of the Villa Stein as seen in volumetric form (from Colin Rowe's *Transparency: Literal and Phenomenal*)

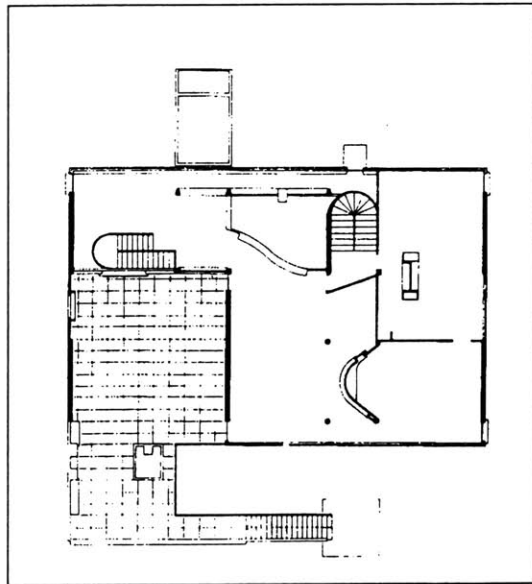


Figure 2-9: The internal plan organization of the Villa Stein contradicts that of its initial visual perception from without (from Colin Rowe's *Transparency: Literal and Phenomenal*)

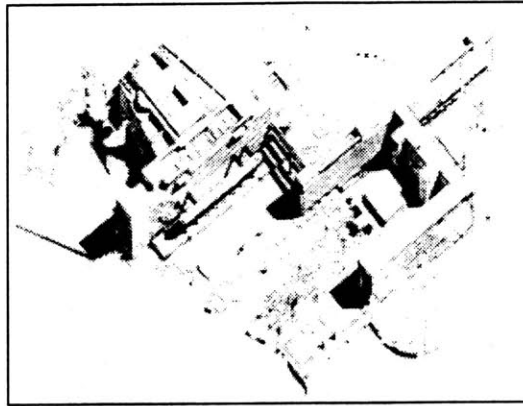


Figure 2-10: Axonometric view of the Palace of the League of Nations (from Colin Rowe's *Transparency: Literal and Phenomenal*)

and this gridding of space will then result in continuous fluctuations of interpretation.²⁰

Rowe's initial discussion of phenomenal transparency is strongly suggestive of the experience of architecture as a kind of dialogue. His statement, "there is a continuous dialectic between fact and implication" can be rephrased to read "there is a continuous dialectic between object and interpretation."

His analysis of the Villa Stein is expressed in terms of virtual readings of the building gleaned from certain fixed viewpoints. An admission of the role of movement in the communication of phenomenal transparency is addressed later in the same essay where a brief analysis of Le Corbusier's project for the Palace of the League of Nations (figure 2-10) describes the implied interpenetration of spatial volumes experienced in an observer's approach to the building. Here, volumes of space are said to be phenomenally articulated by their progressive "lateral sliding" as the observer moves through forecourts of variously greater and then more confined lateral spatial extension (size and shape)(figure 2-11). We have all had the experience of a sudden sharpening of the peripheral vision when entering into a space such as a park or an urban plaza from within the confines of a narrow city street. In Le Corbusier's project one can detect a highly conscious effort on the part of the designer to manipulate just

²⁰[24, pp. 169-170]

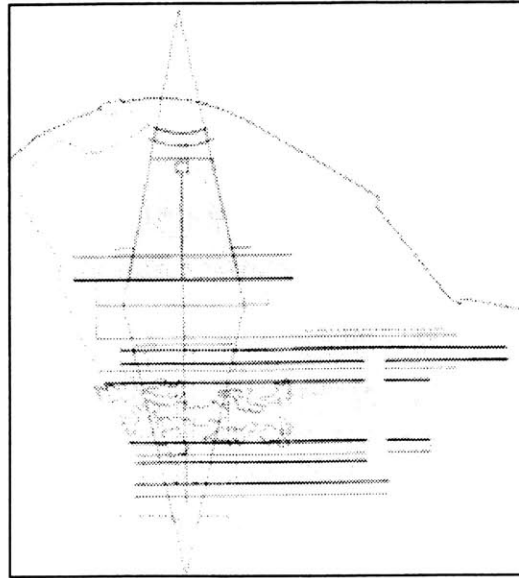


Figure 2-11: Superimposed over a plan of the Palace of the League of Nations are shown indicators of the perceptually apparent shifting planes of the building's masses (from Colin Rowe's *Transparency: Literal and Phenomenal*)

such dynamic modulation of peripheral depth from narrow to broad to narrow to broad, etc. This sliding effect is an intriguing example of the dialogue, now between a moving observer and the dynamically revealed objects within her optic array.

Rowe's phenomenal transparency in this second sense is productive of parralactic effects not unlike those described by Gibson in the juxtaposition of perspective structure and invariant structure that confirm the relatively stable existence of space and material objects based on their changing visual composition as we move about (to be elaborated upon in section 2.2.3). Colin Rowe's analysis of this phenomenon drives explicitly at space as the medium for an exchange between an observer and an artifact consciously fashioned to stimulate her awareness of its own goodness while Gibson focuses on the array as a panoramic surface of articulated shapes. The concepts of "subjective contours," and "phenomenal transparency" both contribute to an understanding of the interactive experience of environmental (and specifically architectural) constructs.

2.2.2 Film and Fragmentation

It can be argued, following on the leads of both Gibson's and Rowe's dynamics of perception, that the experience of architecture rarely involves instantaneous perceptual revelation of itself as a whole, like a small, transparent, isolated object suspended in space. Rather, the experience of architecture is sequential and interrelated through time and memory. The gradual spatial unfolding of a building in one's experience of it can be effectively simulated in the art of film. An investigation of certain parallels with this media can help further illustrate the dialectic of architectural experience as integrally related to the interpretive divisioning of buildings into their progressively smaller and larger parts.

Two levels on which the structure of a film can be read are the total narrative content of the work (its overall framework or story) and the individual events within this overall framework. The narrative can be manipulated in innumerable ways but the point of the story must somehow, in the end, be told. Gibson refers to this whole and the discrete units within it as a composition of "virtual events joined together."²¹

The nested levels of structure within a film correlate to just such virtual events. Individual images composed on the screen are the means by which the overall story is communicated. Like the fundamental mechanics of paint on the artist's canvas, the arrangement of two-dimensional graphic imagery on the movie screen makes or brakes the entire film. The specific qualities of technique and screenplay determine the effectiveness of the communication of individual scenes and, thus, ultimately the whole work. This same fundamental relationship between the part and the whole is strongly apparent in architecture wherein the detailing of individual parts ultimately decides the organic efficacy of the whole building.

Within the structure of a movie scene, meaning is suggested through precise control of the viewer's optic array. Rudolph Arnheim has noted that the way in which the visual field is composed in film and the way it changes offer the possibility to extract the unfamiliar out of the familiar objects that are portrayed, resulting in a

²¹[10, p. 297]

kind of celebration of the common, a revelation of the profound in what, in the course of our everyday existence, may be considered banal and ordinary.²² The movement of the camera relative to the objects it is filming, showing them as distant or close up, isolated or interconnected with other things, or from an unusual vantage point, can produce startling visual effects.

Essential to the film's structure at the level of individual scenes is the concept of *montage*. Some of the principles of montage which are especially applicable to the experience of architecture as well as film are sequences of long, rhythmic shots (one logically following the other in time and space), movement of attention from one detail to its larger context, movement from a certain composition to a detail within it, succession of apparently disparate detail shots (or the juxtaposition of apparently unrelated subjects), succession of related details within a scene, sequential shots suggestive of a change of location, sequential shots suggestive of the description of a single place or thing, contrast of shape, contrast of movement, contrast of inferred meaning.²³ These characteristics of visual montage in film have the ability to manipulate and mold the apparent meaning of the scene through the observer's linking of them together into meaningfully rich, larger coherent units.

If strips of film are joined one to another, it is often observed, especially with really good montage, that they do not simply stand "additively" beside one another but take on quite different shades of meaning through this juxtaposition.²⁴

The associations that the viewer makes with these fragmented images projected on the screen comprise a kind of dialogue that contributes to a viewer's understanding of the essential meaning of the film.

In architecture, as in film, parts within larger organizing frameworks can sometimes appear out of context or fragmented when experienced as isolated from the other "scenes," divorced from or poorly integrated with the overall "narrative line."

²²[5, ch. 2]

²³[5, pp. 94-98]

²⁴[5, p. 98]

Consider that from an exterior view one may get glimpses of interior elements through the windows of a building or through its courtyard gate, for example. The partial surfaces seen in these views of walls and openings and ceiling patterns suggest a layering of space similar to that described by Rowe in the example of the Villa Stein. But, an incomplete picture of their full extent is thus painted and their significance within the overall building order may be brought into question. Similarly, from an interior vantage, due to the limitations of the enclosed optic array, a column's or beam's full extent is often not visually obvious. It may extend behind and above and below the walls, ceiling and floor of the room. Visual ambiguity of the natures of such parts: their extent, inner composition, function, and links within the overall building is what initiates their dialogue with the observer. The observer must interpret these characteristics (with data which is always incomplete) and glean their status as parts acting within a larger assembly.

Fragments not revealed to direct view are often as important as those that are shown. The unknowns must be inferred by the observer (perhaps subconsciously) based on the suggestions of the visible parts and based on past experience and common sense. A reliance on "commonly held assumptions" at this level of interaction suggests the deep culture-bound predispositions involved in perceptual interpretation. They form our traditional understandings of, for example, where to find an exit or what might lie behind a door or how to get to the upper floor. Clues to this kind of information are implicit in the unfolding of the ambient optic array. Analogous are our assumptions about how the story of a film might proceed based on the context of what is happening now, what has happened up to present and what is likely to happen next. Here the audience can be said to participate in the dramatic unfolding of a film in the same way that architectural experience requires a "filling in the blanks," so to speak.

The beauty of this kind of interaction, where the observer's interpretation of the probable nature of the whole is the basis of her concept of it at any given moment, is that her understanding of both what has occurred and what is likely to occur is constantly changing. Since at any given time before the experience is "complete,"

the true nature of the artifact is not wholly apparent, this dialogue is driven by a continual changing of the observer's knowledge of the whole, and thus a continual readjustment of the values of everything that has been experienced in the past (everything that fits into the whole). Events taking place within architectural spaces can be thought of as scenes within the larger organization of the building. For the observer of architecture, experiencing it in real time, there is the expectation that some sort of continuity between the individual episodes of the building will integrate the experience of the whole thing. These expectations may be pragmatic in nature as when one expects to accomplish some predetermined task: attend a seminar, buy groceries, make transactions on a bank account, etc. But they may also be visual and spatial in nature. We expect, for example, that the interiors through which we pass will be recognizable by their form and that the component parts of the buildings which we encounter will visually confirm to us that they are, in fact, what they seem to be: a kitchen that is apparently a kitchen, a roof that is apparently a roof, an auditorium that is apparently an auditorium, a corridor that is apparently a corridor, etc. When an architect studies an existing building, each successive revelation of the nature of one of its parts changes his concept of the nature of the whole thing.

In film, it was mentioned that the various scenes are ordered toward the coherence of some overarching theme or story. A similar imperative is usually upheld in architecture. Segmental progression through spatial "events" which are contributory to the whole are permanently choreographed in film however, whereas in architecture, the possibilities of sequence are not so strictly predetermined. As architects we anticipate the uses of the buildings we design and in this respect we do exert a certain control over the order of their experience. We try to anticipate and, in a sense, loosely choreograph the interactions which might take place within the spaces that we create according to our own understanding of how different parts of architecture are interpreted and how the internal interactions between these parts convey their usefulness to the observer. This organization or "selective choreography" of the interconnected parts and spaces of architecture is not bound, as in film, to the dictates of the director's linear stringing together of a composition. The specific way in which

an observer experiences a building, in dialectic interaction, is not something to be controlled rigidly. Rather, the stage is to be set only as a background against which dialogue can occur naturally. The choices the architect makes are only the beginning of an infinite number of possibilities for the experience of the final work. The experience of the parts in dialogue with each other originates an additional tension between their interpretation as at once distinct, complete, and definable entities but also as subservient and inseparable fragments of something yet larger. This interplay between what are seen as wholes and what are seen as parts is enlivened by the frequent ambiguity as to what is a part of what, brought on by our continually changing conceptions of their scale and order relative to a dynamic environmental context. Unique individual interpretations of the architectonics of a building will always outnumber those envisioned by its designer.

2.2.3 The Motion of the Parts

The movement of the observer in relation to the parts of a building creates Gibson's "flowing visual array" described above. This phenomenon is dialectic in that neither with the observer alone nor with the objects alone does the significance of their encounter reside. Rather, they work interdependently, defining each other through an interactive experience. Gibson makes this point in *The Ecological Approach to Visual Experience*:

...information about a world that surrounds a point of observation implies information about the point of observation that is surrounded by a world. Each kind of information implies the other.²⁵

When objects within the changing optic array are set in motion by the locomotion of the observer, the unique and changing view of elements thus initiated is called *perspective structure*.

The concept of perspective structure is based on the "point of view" of perspective geometry. Note that having a point of view is neither a phys-

²⁵[10, p. 75]

ical nor a mental fact, but an ecological one. From a given, single point of view any layout produces a unique optic array, with some parts hidden by others and with particular perspectives of each unhidden face visible. These occlusion relationships and perspective forms change with any movement of the point of view. The changes that occur as a result of locomotion constitute the perspective structure of the optic array.²⁶

Paradoxically, it is through their movement and change in perspective structure that we detect the material stability of the parts, their *invariant structure*. The distinguishing of invariant structure – that which tends to persist over the observer’s displacements – is made when the frozen perspective structure of a still image “begins to flow.”²⁷ In this sense *what* we see is not predicated upon a particular view of it per se but through our own moving visual interaction with it. Here, ontological distinctions of the parts of architecture, as coherent and stable objects in and of themselves, are suggested by their visual differential movement within a flowing array of visually contrasting objects.

Evidence for the material stability of the objects themselves, i.e., their invariant structure, is detected by way of their characteristic perspective structure. In the example used by Gibson, an observer’s changing perspective view of a table top reveals various trapezoidal shapes (due to its perspective diminution) in the optic array. A changing view of the object, however, confirms its invariant existence as a stable, rectangular shape. The perspective structure of the table top consists of a shifting trapezoidal surface while its underlying invariant structure is clearly a solid rectangular entity. Persistent things become apparent as such only through their apparent change when viewed from different points of view.

Perspective structure (as revealed in invariant structure and parallax movement) is also ordered in various hierarchical scale levels within the environment. At the anthropometric scale of the individual table, perspective structure of the table’s legs with the observer’s changing point of view reveals them as solid objects. Their

²⁶[20, p. 290]

²⁷[10, p. 74]

coherent displacement relative to the table suggests their distinction as parts of the whole table. Similarly, the perspective structure of the table as a whole and its overall parallax motion with respect to the room it occupies suggests *its* status as perhaps one of many constituent parts of the room. Perspective structure within the optic array reveals invariant structure which in turn participates in parallax motion at yet higher scales of reference. The perception of a range of scales of material objects embedded one within another in the optic array has been referred to as “nesting.”²⁸ The dialectical nature of the observer’s perception of such an environment involves 1) the revelation of invariant structure through the perspective structure of solid material things and 2) the observer’s interpretation of distinct parts embedded within the optic array based on their invariant structures in relative parallax motion.

Practical distinctions of material parts in their larger contexts are suggested both by information inherent in the material arrangements of the environment and by the observer’s interaction with and interpretation of this layout. A mutual complementarity of the perspective structure contributed by the observer, and the invariant structure given by the solid objects in the environment is cited by Gibson in support of the notion of visual perception as dialectic interaction:

Although they specify different things, locomotion through a rigid world in [perspective structure] and the layout of that rigid world in [invariant structure], they are like the two sides of a coin, for each implies the other. This hypothesis, that optical change can seemingly specify two things at the same time sounds very strange, as if one cause were having two effects or as if one stimulus were arousing two sensations. But there is nothing illogical about the idea of concurrent specification of two reciprocal things. Such an idea is much needed in psychology.²⁹

Edward Reed’s comments on this topic are also helpful:

Perspective structure in the optic array specifies the environment of one observer, what a single individual would encounter along his or her path

²⁸[10]

²⁹[10, p. 76]

through the world. Invariant structure in the array specifies the environment of all observers, what any observer would see on any path in the locale. Note that what is specified in both cases is an animal-to-environment relationship. Just as the relationship between the environment and the animals within it is one of mutuality, so all forms of optical information specify some observer's being in the world. Perspective structure does not specify the self independent of the environment, nor does invariant structure specify only the environment, although it does specify things independently of the self –a fundamental fact for social psychology. Vision is always a mixture of proprio- and extero-ception. Perspective structures specify where we are heading, and invariant structures specify what we are heading toward.³⁰

Within this world of mutually dependent “reality” and the subjective, mobile, visual experience through which it is perceived, the overlapping and occlusion of objects within the array play an important role. Discernment of the volumetric nature of solid things comes about through the movement of perspective structure and parallax. Changing surface occlusions, for example, inform us as to what is hidden and what is concealing, as Reed notes:

What persists across observer movement is the *connectivity* and the *discontinuities* specifying the layout of the environment of all observers. What changes is the momentary separation of the hidden from the unhidden. As an observer moves along a path through a cluttered environment, a specific set of vistas is revealed and concealed. Observers can thus perceive the limits of what they can see now (the temporary occluding edges) and also see what could be seen by moving to a new viewpoint.³¹

Visually fragmented parts of the array are presented from any single point of view for the cognitive completion of the observer based on information gleaned from many

³⁰[20, pp. 290-291]

³¹[20, p. 292]

other points of view. Movement of the occluding edges of overlapping shapes is their essential contribution to the dialogue, while interpretation of their masses and volumes is the role of the observer. Gibson writes that the movement of the observer is the mechanism for informing about surfaces which are partially occluded. It should be noted that, for opaque, material objects, perception of all surfaces at once is impossible. Our visual understanding of all of their sides is accomplished only with a changing view of them.

Any facet, any surface of the layout that is progressively hidden during a displacement is progressively unhidden during its reversal. Going out of sight is the inverse of coming into sight. Hence, occluding and occluded surfaces interchange. The occluding ones *change into* the occluded ones and vice versa, not by changing from one entity to another but by a special transformation.³²

Our ability as observers to move around in the environment as we observe affords many times the visual sensory information that can be received from the “snapshot vision” that is often assumed appropriate for the depiction of architectural space. Both the changing states and relative positions of various objects we experience as well as our own movement around and within them combine to verify the reality of surface texture, pattern, shape, and volume. Gibson uses the fact of our ability to observe our surroundings from changing vantage points as evidence that “the environment surrounds all observers in the same way that it surrounds a single observer.”³³ In affirmation of those inherent human assumptions about the existence of the larger “whole,” Gibson argues that we all do, indeed live and experience the same world.

The fact of a moving point of observation is central for the ecological approach to visual perception, and its implications...are farreaching.³⁴

³²[10, p. 78]

³³[10, p. 43]

³⁴[10, p. 43]

2.2.4 Affordances

Perceptual experience itself is a kind of system because it involves a mutually interactive process of discovery. The perceptual abilities with which we are endowed provide us with ways of looking at things and, in fact, initiate the dialectic engagement between the objects of perception and our interpretations of them. The interdependent relationships we perceive among objects in the environment is closely aligned with the relationship between ourselves and the environment we experience.

It should not be surprising, then, that when we observe the world around us, the most important of its aspects that we are inclined to thus perceive are in fact *systems* aspects, i.e, purposeful interrelationships between the objects of the environment as a coherent unity rather than as independent and unrelated phenomena. We notice, for example, not just that “that is a table” but more importantly, “that is a table which possesses certain properties due to which it is useful, and it works *with* the other objects around it.” The table is a simple example and yet the quantity of information that is implied by it— embedded implicitly in our perception of it— points to the remarkable abilities we have as humans to interpret, even subconsciously, the things around us as systems. The very coherence of an object, making it identifiable as a single thing, involves more than the visual phenomena in which it participates as a material thing. It carries with it a network of associations and useful qualities for the observer.

The observation of familiar things reveals in them an immediate existential unity that encompasses all aspects of their form and matter (even though we are not perfectly aware of all of these aspects). When confronted with unfamiliar surroundings we seem to have an incredible ability to automatically adapt by searching for the order that ties things together. Part of the process of adaption is the interpretation of systems. Christopher Alexander writes:

When we are confronted with a complex thing, we often begin with nothing more than a feeling or a ‘sense’ that it functions as a system. Driven by this feeling, we then try, painstakingly, to abstract out just

that holistic behaviour which seems essential, and those interactions which cause the behaviour. This is an iterative process. It begins with feeling, and sensing, and only turns to thinking later. Start with some aspect of life so interwoven that you feel in your bones it must be a system, only you can't state it yet—and *then*, once you can feel it clearly, then try to pin the system down, by defining the holistic behaviour you are discussing, and which interactions among which parts create it. But feel it clearly first before you try to think it.

The systems point of view is not neutral. It will change your whole view of the world.³⁵

Alexander's comments suggest a strong relationship between our sensual encounter with the world and our search for *systems* in the world we thus perceive. They also suggest a reliance not on "seeing" alone but on the "feeling" for space and materials as a kind of extended haptic perception.

Another way of comprehending our experience of the world as purposeful or "designed" is to consider the ability of the environment to communicate what James Gibson termed, *affordances*.

The affordances of the environment are what it *offers* the animal— what it *provides* or *furnishes*, either for good or ill.³⁶

By *affordances* Gibson means

something that refers to both the environment and the animal in a way that no existing term does. It implies the complementarity of the animal and the environment.³⁷

Affordances are properties taken with reference to the observer. They are neither physical nor phenomenal.³⁸

³⁵[2]

³⁶[10, p. 127] "The verb *to afford* is found in the dictionary, but the noun *affordance* is not. I have made it up."

³⁷[10, p. 127]

³⁸[10, p. 143]

The uniqueness of Gibson's term stems not from an object's absolute, inherent symbolization of its own utility to the observer. Rather, in close accordance with the communicative dialogue between the observer and her environment, an affordance is the apparent useful meaning of an object in the context of the observer's particular encounter (or remembered encounters) with it. In other words, it is the observer's recognition of the object's value "for benefit or injury" *as it is perceived by her*. Affordances are a product of the interaction between the physical existence of the object and the observer's phenomenal perceptions of it rather than either one of these taken in isolation. In this sense the meanings of what one encounters in the visual array are relative to *how* one encounters them. How we interact with and thus complete the fragmentary visual information provided by the objects is made meaningful through the spatial medium that defines both sides of this dialogue—the spatial medium of the interaction itself. In the realm of architecture, Gibson's affordances are these useful meanings communicated between the parts of buildings and the observer. Furthermore, in contradistinction to the view postulated by Koffka, that the useful meaning of an object is predicated on the needs and desires of the observer, Gibson states that

An affordance is not bestowed upon an object by a need of an observer and his act of perceiving it. The object offers what it does because it is what it is. To be sure, we define *what it is* in terms of ecological physics [(practical, experiential physics)] instead of physical physics [(scientific, reductivist, molecular physics)], and it therefore possesses meaning and value to begin with. But this is meaning and value of a new sort.³⁹

The meaning Gibson refers to is the larger ecological one that admonishes a view toward the interpretation of the observer's direct experience and a kind of communal agreement as to the "objectivity" of human experience in general. Architectural meaning may be thought of as the result of the affordances of locomotion, manipulation of parts, shelter, gathering, conversation, worship, etc. An affordance can be

³⁹[10, p. 138]

manifest as an emotional response to a particular perceptual experience of architectural space such as a sense of awe, delight, or even fear. What things afford and how we experience them are interdependent aspects of the perceptual system.

The ability to perceive space as useful, though not a human sense perceptual capacity in and of itself, certainly draws on the information received in all of the senses. It reinforces them. The idea of the “body image”, stemming from an innate understanding of the solid “materiality” of our human bodies and the dialectic relationship between space and solid matter, supports the notion of a sense of the utility of space as intimately related to our overall perceptual system.

The phenomenon of figure-ground reversals indicates that space is *potentially* solid material and solid material is *potentially* space, though something cannot be both simultaneously. The complementarity of solid and void can be compared to the complementarity of the human perceptual system and the objects that it perceives. It is in the *interaction* between the objective and the subjective, however, that what is at once a dichotomy can also be a unity. The interaction resides at a higher, encompassing scale of reference.

An affordance cuts across the dichotomy of subjective – objective and helps us to understand its inadequacy. It is equally a fact of environment and a fact of behavior. It is both physical and psychical, yet neither. An affordance points both ways, to the environment and to the observer.⁴⁰

Like the two sides of sculpture, object and relief, each co-defining the other: mutual interaction is the *genesis* of the *dialogue* that is both.

⁴⁰[10, p. 129]

Chapter 3

The Forms of the Parts of a Building Structure

3.1 The Distinction of Subsystems

To further understand the objects that we perceive as systems we reduce them into *subsystems* (subordinate or secondary systems within larger systems that contain them) and their constituent parts. We thus generalize and classify parts into hierarchically ordered subsets wherein the parts residing at lower levels combine to make those of the higher categories. In investigating the parts of systems we are interested in their forms both in terms of their geometric, spatial qualities and in terms of their useful, structural behavior. This kind of investigation is especially important in architecture, where a great number of parts are required to account for all of the formal aspects of a building.

The term *building system* in this thesis refers to the entire building including its structural, enclosing, protective, transformational, symbolic, spiritual, psychological and emotional aspects. It encompasses the whole of the most basic human activities, building and dwelling. Being most concerned with the facilitation of the production and use of specifications for a building construction contract, however, this paper can not address all of these issues explicitly. Limiting the discussion to the technical, material aspects of a building system, those with which the construction specifica-

tions deal directly, we can conveniently subdivide the whole building into four broad subsystems:

- its **foundation subsystem**: the objects that mediate between the building and the earth at a particular site, including other changes to the landscape itself;
- its **structural subsystem**: the objects that hold the building up above the ground, prevent it from collapsing, and protect its occupants;
- its interior **partitioning subsystem**: the non-load-bearing, interior space defining objects, furnishings, and interior finishes;
- and its **services subsystem**: the objects that distribute services (air, water, light, power, signal, etc.) throughout the building.

The leap from the perceptual unity of a whole building system to a distinction of its major subsystems is fairly intuitive. In most buildings we know that removing the utility services, ductwork, wiring, piping, etc., will not cause the building structure to collapse. By the same token, one can imagine the foundation and earthwork for a building as differentiated from its superstructure. The distinction between the superstructure of a building and its interior partitions can be somewhat deceiving since it is often not clear which interior walls are load-bearing and which are not. But this distinction can, nevertheless, be made with a little investigation. As with the distinction between smaller, individual parts of a building, the conceptual individuation of one subsystem from an entire system does not construe its total independence. Such an assertion would be in direct contradiction to the meaning of the word *system*. Rather, the distinction of subsystems and parts, both perceptually and conceptually is a means toward an understanding of the individual contributions that they make toward the larger assemblies in which they participate. By definition, these parts are interdependent.

Coming to know the distinct nature of a building system involves developing an understanding of the difference between parts per se and the same parts as *parts of a greater whole*. This implies an understanding of the change in form that a

part undergoes as it is *transformed* from something that exists in relative isolation, cut-off from the other parts, to something that engages itself in mutually interactive, physical relationships with other, similarly purposeful objects. The subdivision of the building as a whole into building subsystems is the first step in a series of hierarchically ordered, conceptual distinctions and classifications of the parts of a building system. These operations will open the door to further investigation of their interdependent relationships and thus an understanding of the organic nature of the building system as a whole.

The subsystems listed above represent only a limited, and somewhat technical, interest within the total scope of a building's interrelated organism, the *whole building system*. In the interests of practicality, however, this thesis will be even more selective about its topic, focusing specifically on the *building structural subsystem*. Hopefully the basic principles elucidated in the coverage of one subsystem can be applied to other subsystems and, in a general sense, to the building as a whole.

The *building structural subsystem*, again, refers to the material aspects of the building which provide for its physical support and protection. It encompasses the building materials, parts and assemblies which, when combined together, make a building object that can maintain its physical integrity in the presence of externally applied loads and its own gravitational weight while also sheltering and supporting its interior contents (including its occupants) against undesirable forces of the outside environment.

In general, the word *structural* is "a name for the effective pattern of relationships in any situation."¹ I wish to admit this broad definition especially when describing, for example, the "structure" of a specifications format in chapter 4. In the context of the physical building itself, however, the word *structural* will mean the load bearing support of a building and its enclosure of the inside from the outside environment.

In some buildings the envelope or exterior skin can be counted as a subsystem of its own. This applies if the basic structural support of the building is relatively independent, from a statical point of view, of the building skin. It can be assumed

¹[28, p. 27]

that the building structural subsystems described in this chapter are inclusive of their exterior skins, unless otherwise noted.

Although subordinate to the larger system in which it participates, a subsystem must still answer to the three basic criteria that Christopher Alexander expressed as conditions for system status. In order to speak of a building structural subsystem as a system at all, we must be able to state the holistic behavior on which we are focusing. The holistic behavior of the building structural subsystem on which I will focus is its provision of habitable, interior space.

The other two conditions for speaking about a building structural subsystem as a system will be satisfied in the course of this chapter. They are, the identity of the parts within the system (to be covered in section 3.2) and the interactions among them which cause the holistic behavior defined above (to be covered in section 3.3).

Typical aspects of holistic behavior of building structural subsystems will be made apparent throughout this chapter. The strength of the whole will be shown to be greater than the sum of its parts taken singly. A change in one of its parts will result in changes to the others. And the stabilization of the whole will be demonstrated to be a result of shared responsibility among many interconnected parts.

In looking at a building structural subsystem, I will be interested in the specific, individuating characteristics of its parts, including both their purposeful behavior and the external aspect or shape that they assume. In short I am interested in its *form*. The shape of a building (or part thereof) is its spatial-geometrical, material disposition as it defines volume. Its purposive behavior hinges on its statical, stress-resisting capabilities. Alexander Zannos uses the term *statical function* in a similar sense. He defines it as “the way in which a form reacts...to loads”² where “loads” are the impacts of all environmental forces on a building, including gravity, wind, seismic, sun, rain, thermal change, vibration, etc. The main stresses induced by these loads in the material parts of a building structural subsystem are tension, compression, bending, shear, torsion, thermal and chemical stress. Both external appearance and statical performance are aspects of the form of a building and of its parts which must

²[30, p. 10]

be addressed in construction specifications.

3.2 The Classification of the Parts of Building Structural Subsystems

Distinguishing between the parts of a building structural subsystem based on their hierarchical subdivision in levels from that of the building whole, at the highest, to that of its smallest pieces, at the lowest, will help to generalize the parts into categories of like or similar status within a common framework. In descending order, beginning at the building structural subsystem, these are the *schemes* level, the components level and the *elements* level. Building structural schemes are the basic units of three-dimensional building structure: the schematic units of habitable space. Elements, at the other end of the spectrum, are the smallest, generally repetitive units of a building. They are the raw or “stock” materials and supplies (including many standard, commercial, pre-fabricated parts) out of which a building is built. Components, in between these two, are the parts that are comprised of elements and that combine to make schemes.³

In the subsections that follow, I will examine in more detail the typical forms of the members of each of these building parts levels. They are the basis of my analysis of building structural systems and will, as well, serve as the principal organizational subdividers in the alternative specifications format proposed in chapter 4. The basic definitions of the levels are expanded below.

³This distinction of the parts of a building structural subsystem bears some resemblance (but is not identical) to a differentiation between *structural scheme*, *structural principle*, and *structural element* devised by Amine Klam, Eric Dluhosch, and N. John Habraken at MIT in the early 1980’s and documented in Klam’s S.M. thesis of 1982, *Space and Material: Towards an Architectural Typology*. Klam defines *structural element* to be the elemental, non-configurational building blocks of *structural principle*. *Structural principle* refers to “a configuration of elements that performs a certain structural role: spanning, transmitting load, resisting forces.” [13, p. 34] *Structural scheme* then “concerns a configuration of structural principles that performs a space-enclosing, or at least a *space defining* role.” [13, p. 34].

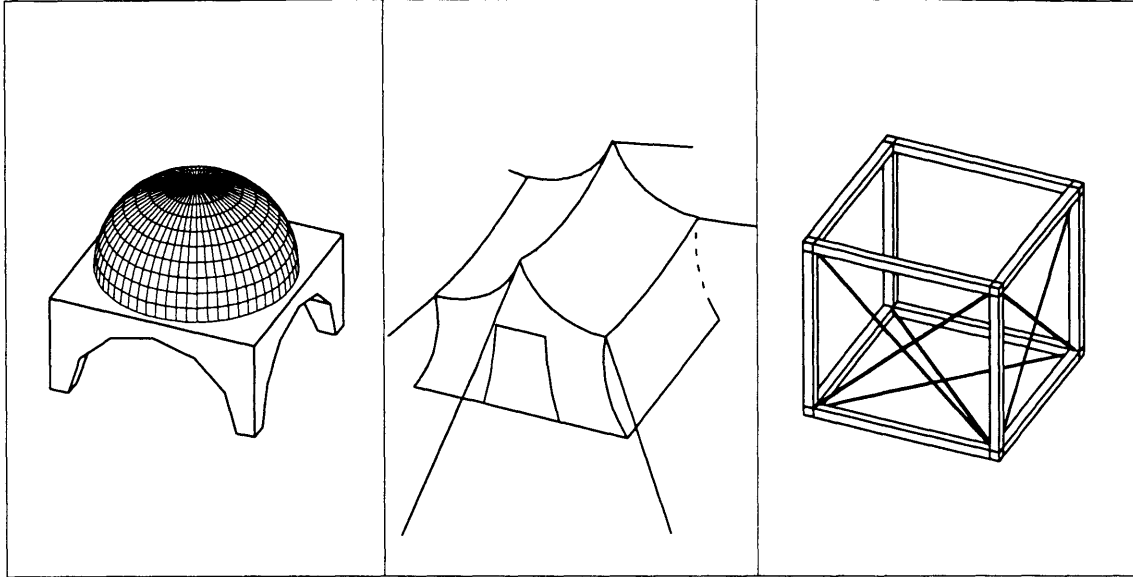


Figure 3-1: Examples of building structural schemes: vault and dome, fabric covered tent, simple braced frame

Schemes

Scheme is the largest basic module of a building structural subsystem (see figure 3-1). Our ability to distinguish schemes is intimately related to our sense of the *modularity* of constructed (or “artificial”) space as encountered in direct, perceptual experience of buildings. Two overriding characteristics of building structural schemes are:

1. the manifestation of fundamental three-dimensional, habitable space which we can perceive in our interactions with buildings, and
2. the employment of material members to the best of our knowledge of their behavior and our abilities to build with them.

In its pure manifestation, a structural scheme can comprise a complete structural subsystem in and of itself, affording in a single “compact” unit the resistance to externally applied loads from any direction. Examples of this condition are seen frequently in the primitive architecture of huts and cabins as well as in the “tent” scheme depicted in the middle image of figure 3-1. Most larger buildings, however, are comprised of several structural schemes linked together. Among the examples shown in figure 3-2 are the bundled “tube” schemes of a highrise office building and

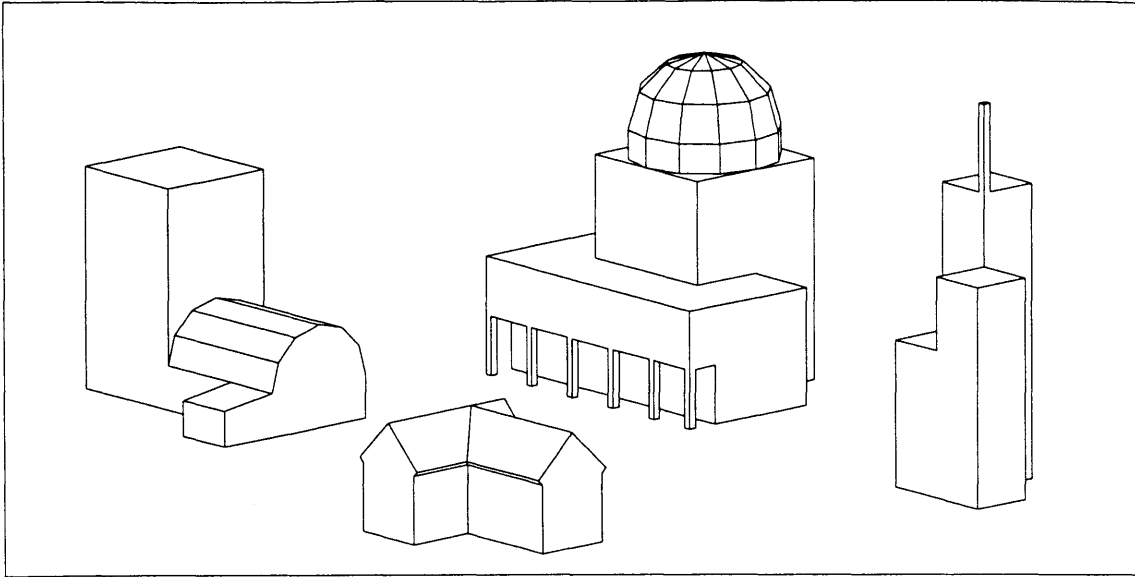


Figure 3-2: Building structures consisting of more than one structural scheme put together

the “wing” schemes that make a large house.

Building structural schemes can usually be further classified as belonging to one of three generic types. These are the *shell* scheme, the *box* scheme, and the *frame* scheme. Figure 3-3 shows examples of these three types.

Shell schemes enclose space by molding material around it continuously, as in a dome or a cave. Often these are built of many masonry elements or are cast out of materials like concrete or plastic. Shell schemes are also buildable out of small linear members like wood or metal sticks which, when densely interwoven into a matrix, can constitute a transparent version of a solid masonry dome, using much less material. Numerous examples of such shell structures can be seen in the geodesic domes of R. Buckminster Fuller.

The “liberation” of the vertical wall components from the roof and floor components of a shell structural building scheme transforms it into a box. In addition, the “cornered” articulation of the flat, planar walls thus suggested makes the box readable in terms of its discrete “panel” units, joined along their edges. This is the genesis of the box building structural scheme. A further distinction of box schemes over shells lies in the stacking ability of box units (shown in the middle-right image

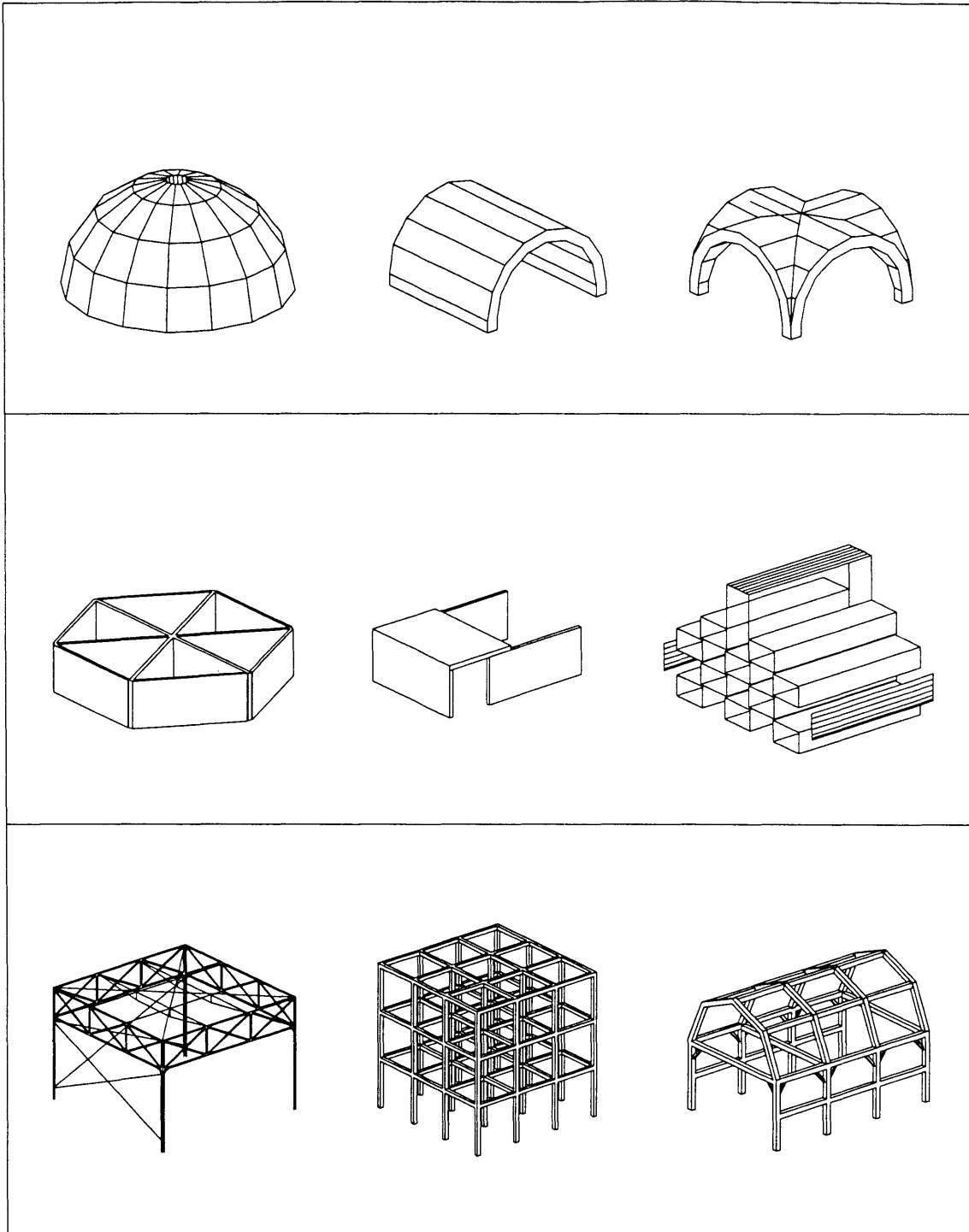


Figure 3-3: Examples of *shell* schemes (top), *box* schemes (middle), and *frame* schemes (bottom)

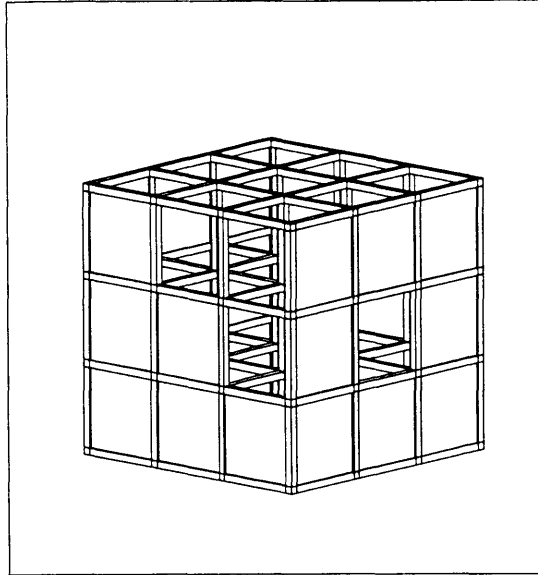


Figure 3-4: A frame scheme with light cladding panels inserted into it

of figure 3-3). Box schemes can also singly comprise the structural subsystem of a building, as is the case in the New England salt box house or in the mobile home, for example.

In the frame structural scheme type, massive and planar shapes of the shell and box respectively are resolved into exclusively linear elements, interfacing at corner points. The apparent dissolution of the overall volumetric coherence of this structural scheme, created by the free penetrability of the frame, is accompanied by a tremendous flexibility in its potential articulation. It can be clad in thin surface panels (see figure 3-4) and it can even become an organizational matrix into which other schemes are nested, as in figure 3-5, where individual boxes are inserted into an overarching building schematic frame. The flexibility of the frame in accepting structures of other schematic types suggests a more general tendency toward single structures which combine aspects of more than one scheme type (see figure 3-6).

Elements

Building elements are the “atomic” units of design by an architect and assembly by a builder. They are the basic pieces or “raw materials” out of which a building is made. They can be either naturally-found objects, like stones and branches, or they

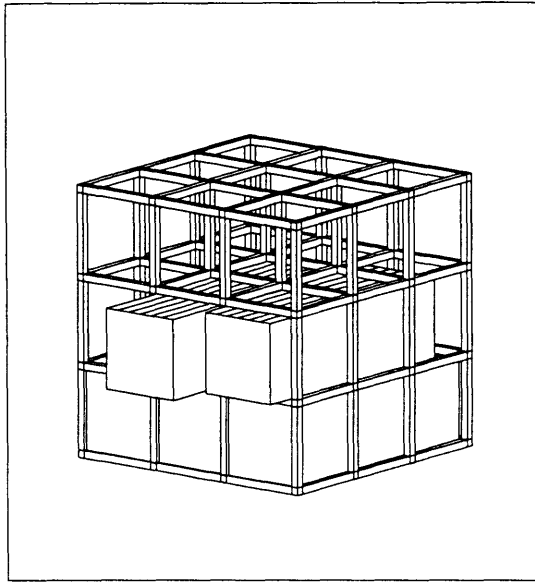


Figure 3-5: A frame scheme with box units inserted into it

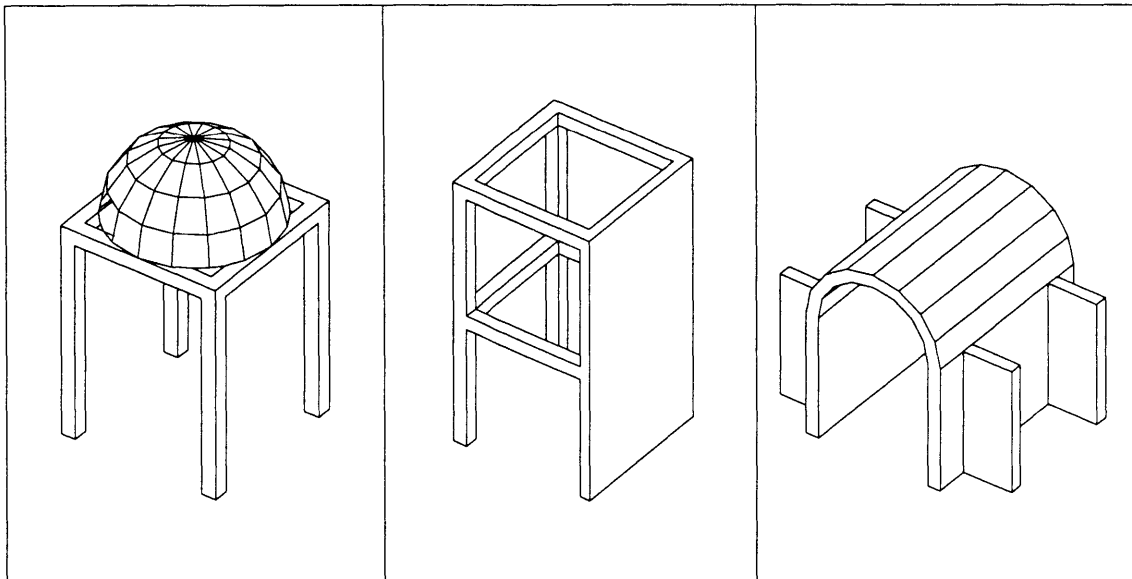


Figure 3-6: Building structural scheme “hybrids:” *shell and frame* at left, *panel and frame* in the middle, and *panel and shell* at right

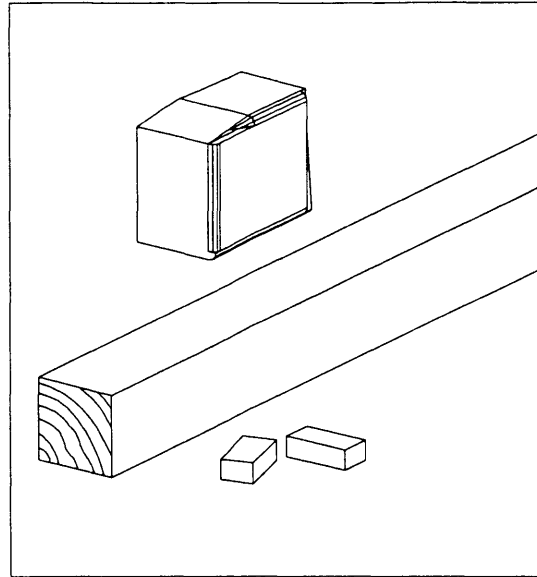


Figure 3-7: Examples of traditional building elements

can be pre-manufactured, mass-produced products which are procured off-the-shelf, like steel WF beams and bar joists. In this sense, elements represent a level of parts form below which the architect exercises little design control, except that of selection.⁴

Traditionally, the number of different element parts available to the architect has been limited to simple raw materials like bricks, stones, and timbers (see figure 3-7). Since the industrialization of building construction (beginning roughly in the late eighteenth century and continuing until today) the number and formal complexity of element parts available to architects, engineers, and builders has increased dramatically. Figure 3-8 shows just a few of the elements we commonly see in “custom-built” construction projects today. The range of possibilities for large scale element standardization and marketing that is offered by the industrialization of building parts production is striking. Among the elements of construction often employed today are pre-manufactured roof and wall panels, dormers and cupolas, modularized bathrooms and kitchens (from the partitions and services subsystems), and even entire curtain walls.

⁴Elements can, of course, be modified in any individual application. A steel joist can be painted, for example, and a wood stud can be cut to size, but these changes (being *accidental* rather than *essential*) do not alter the *element* status of the part.

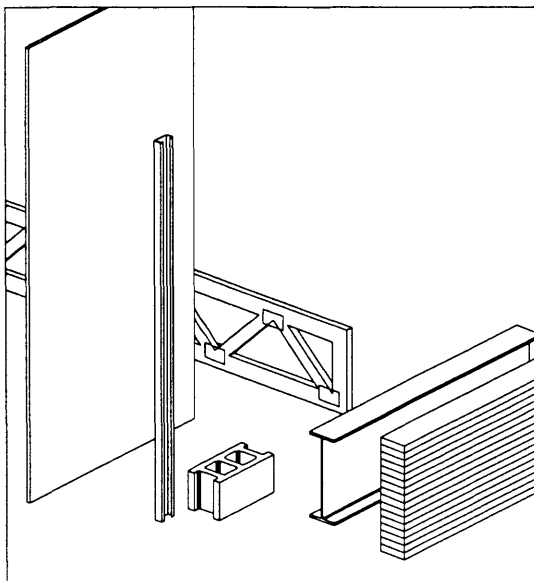


Figure 3-8: *Industrialized building elements*

Although the range of sizes that elements may assume is broad, the importance of their somewhat relative distinction (as elements) is critical from the perspective of both the architect and the builder. In the specification of the parts of a building, the builder must make a sharp distinction between the parts of the building that he is directly responsible for fabricating and those parts which are to be procured from a supplier's inventory of standard, mass-produced items, and simply installed. The architect makes this very same distinction in formulating a set of contract documents for a building. In specifying the makeup of the parts of the building, he need not be explicit at the level of the elements selected for use in the project. Although *specificity* is required throughout the contract documents, *explicitness* need only extend to that level of detail at which the standard specification of an outside, commercial manufacturer can take over. Elements are "stock" items that are *selected*, not designed, by the architect or owner.

The relativity of this definition becomes apparent when one considers that for a manufacturer of steel bar joists, for example, the atomic units of production are raw steel bars rods and angles. The manufacturer of the joists does not *make* the bars but buys them from a supplier of raw materials. Analogously, from an architect's or builder's point of view, the bar joist itself is atomic. It is not designed by them but

rather is procured as a “raw material,” an *element* of construction out of which larger assemblies (components and schemes) are specially designed and constructed. Implicit in the architect’s or builder’s selection of this item for a project is the understanding that it is the bar joist manufacturer’s responsibility to provide a product whose form is consistent with the description given in the manufacturer’s literature.

An increasing reliance on industrial, mass-produced building elements that can be simply chosen and then installed on-site, has had a major influence on the design of buildings in our time. Charles and Ray Eames designed complete houses made entirely of industrially produced building elements such as those one finds in the Sweet’s catalog in the late 1940’s. In the Eames houses these elements are combined in custom-built components and schemes with great skill and architectural sensitivity.

Components

In the architectural conceptualization of a building and increasingly in the process of construction itself, one doesn’t necessarily think of a building whole as merely a conglomeration of elements. Even in the perceptual experience of architecture we distinguish between a floor and a wall, though in most cases neither may properly be called an element (an atomic unit), much more readily than we do a joist and a stud, which may well be elements. At the same time a wall can not qualify as a scheme by itself because it does not constitute a three-dimensional, interior, habitable space.

The component level of building form is the intermediate category of parts distinction within which are typically considered (among other things) the floor and the wall, for example. Components are parts which go together to make schemes. But unlike elements, they are specifically designed and fabricated for a particular building. Typical components are walls, floors, roofs, porticoes, buttresses, bays, lean-to’s, panelized veneers, plinths, pediments and gables, arches, trabeations and framed openings, to name a few. The architect, owner, and builder take responsibility for the design and construction of components. Their makeup must therefore be *explicitly* specified in the contract documents for any building in which they are used. Illustrated in figure 3-9 are some of the more common components of building

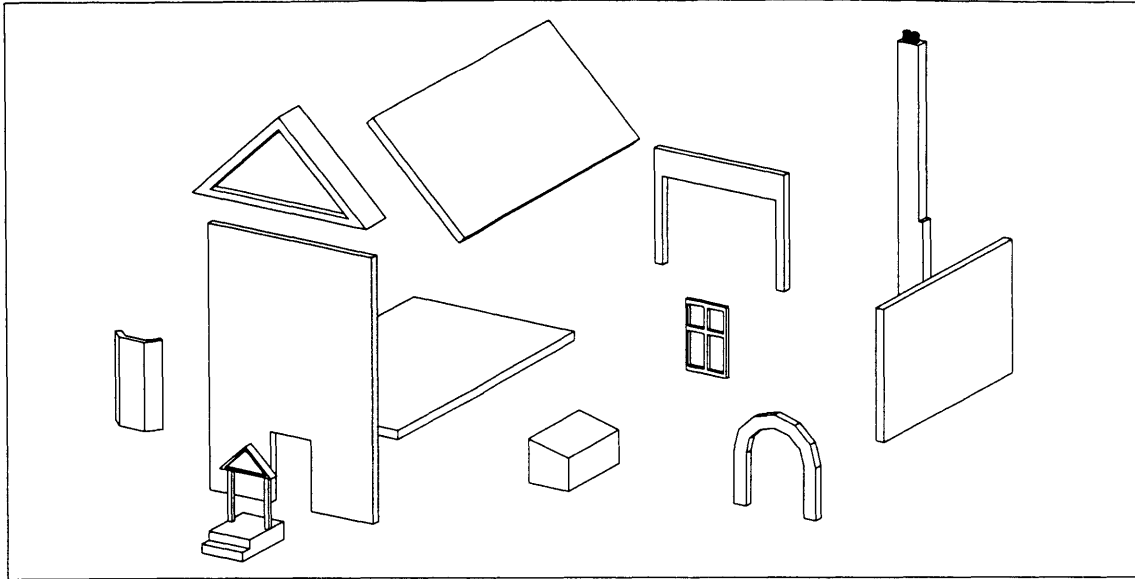


Figure 3-9: Some typical building structural components

structural subsystems.

It is important to note that the primary distinction between elements and components is not that one is fabricated off-site and the other is assembled on-site. Rather, from the point of view of both the architect and the builder, the difference lies in the fact that components are custom designed items for a particular building project. They are specially made, whereas elements are merely procured as “stock” items that can be picked out of a catalog, bought in a lumberyard, or found in nature. The location of manufacture of a part of a building, whether component or element, or even scheme, is not at issue in their distinction as such. While it is true that most building elements are manufactured in a factory remotely located from the job site in which they are used, it is also possible to produce elements on location, as is sometimes done in the production of concrete or even in the milling of lumber. Similarly, although building components are most generally associated with on-site assembly, it is increasingly the case that (“one-off”) components are shop-fabricated and transported to the site for erection into schemes.

Finally, it should be added to the general classification of components that, although typically comprised of an assemblage of smaller, element pieces, they can also be constituted of a single element. In this case the element must be significantly mod-

ified as to make it unique to the building –an essentially new object, as is the case in the carving of stone or wood blocks into sculptures and in the casting of concrete into special, custom shapes.

Components form the basic “vocabulary” of architecture at the level of whole building schemes. It follows, then, that they necessarily, collectively become the form of the scheme, even though they lack the necessary criteria to be called schemes when taken individually. This does not mean that the forms of individual components must serve that of the building structural scheme exclusively. One can think of many examples in which the form that a wall component takes is dictated by other concerns, like the service of light, air, and view to the interior of the building, to name only a few.

Their affordance of distinct roles in the service of the whole building system has made components a popular basis for “performance” type criteria in building regulations and standards. Modern building codes, for example, often use what I am calling “components” as the specific objects of their standards criteria: minimum structural capacities, fire resistance ratings, sound transmission characteristics, means of structural attachment, etc. Components can represent the basic units of heavily industrialized construction (see figure 3-10). However, the stereotyping of such *Componentized* buildings as involving cheap, low quality, factory produced goods has nothing inherently to do with the term as I am using it here.

3.3 The Interrelationship of Scheme, Component, and Element

There are unique relationships between elements, components, and schemes in each of the generic scheme types introduced in section 3.2. In the most primitive type, the shell type, there exists an intimate relationship between the basic, repetitive elements (usually stones, bricks, or sticks of some kind) and their schematic form (a dome or vault, for example). It is often difficult to conceive of a distinct *component* level between them. The elements are really combined directly into the scheme.

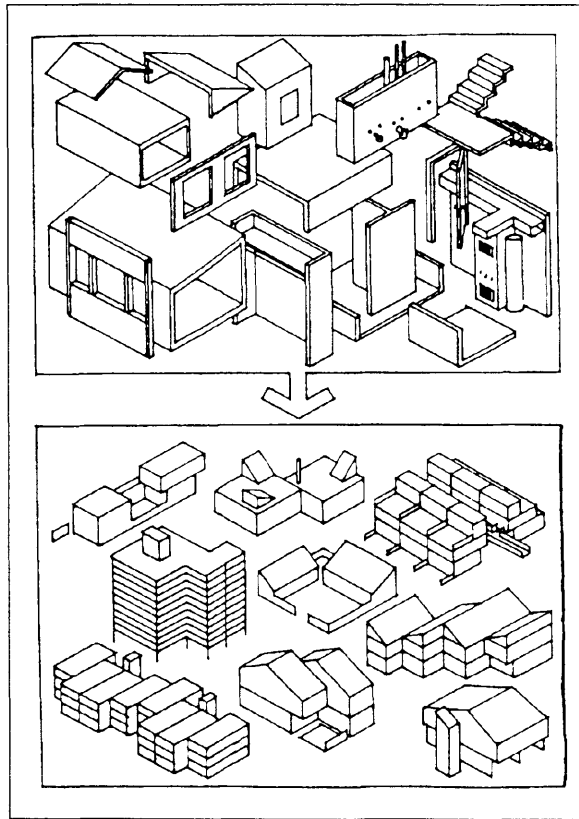


Figure 3-10: Graphic of industrialized “parts” and their combination in buildings
(from Richard Bender’s *A Crack in the Rear View Mirror*)

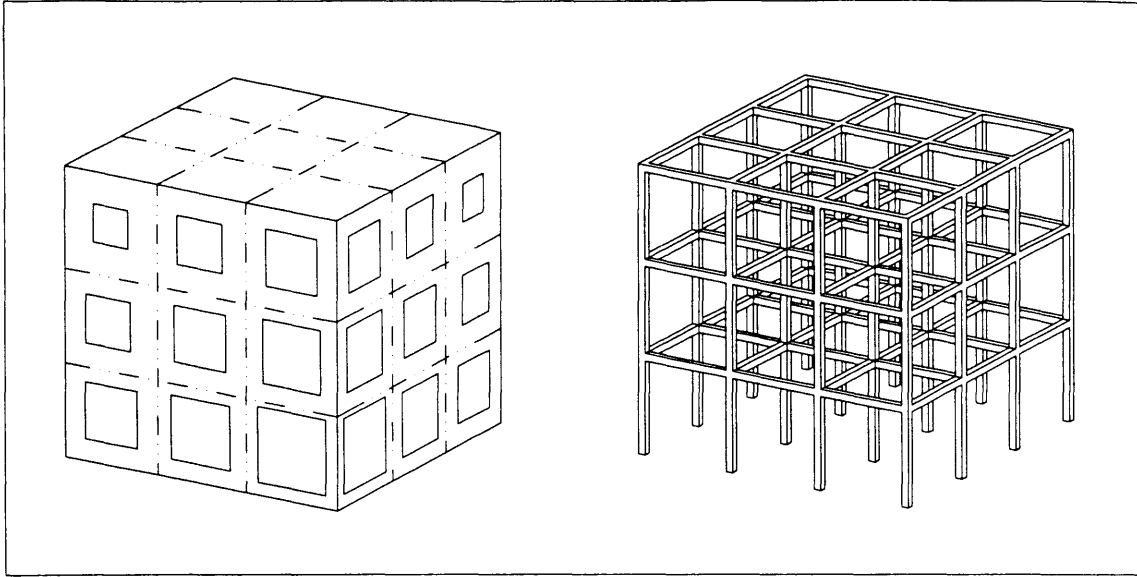


Figure 3-11: A frame scheme is like a box scheme with large punched openings

Much more clearly expressed in the box scheme, on the other hand, is the role of “panel” components which, though usually made up of elements themselves, are nonetheless distinguishable from the box as a whole.

The frame takes an altogether different attitude toward its internal composition of components and elements. Note that in the frame scheme type there is once again a strong relationship between the elements of its construction (its individual beams and columns) and the schematic level of their combination. Unlike the shell scheme type, however, which made a direct leap from element to scheme, bypassing components altogether, the component level within the frame scheme is suggested in its repetitive pattern of trabeated portals (column to beam to column, and so on). The frame also has the potential to suggest its own transformation variously between planar and linear members by varying the proportion of its beam and column width to the open space between them in a kind of “figure-ground” manipulation (see figure 3-11).

The frame itself however can be profoundly evocative as expressed in the Chicago works of Mies van der Rohe, for example, where the rigid steel skeleton’s own internal, mutually interactive element parts distribute loads from any point to the foundation system with apparent efficiency and elegance. Noted by Colin Rowe as both a pragmatic expedient toward inexpensive, easily adaptable construction by its

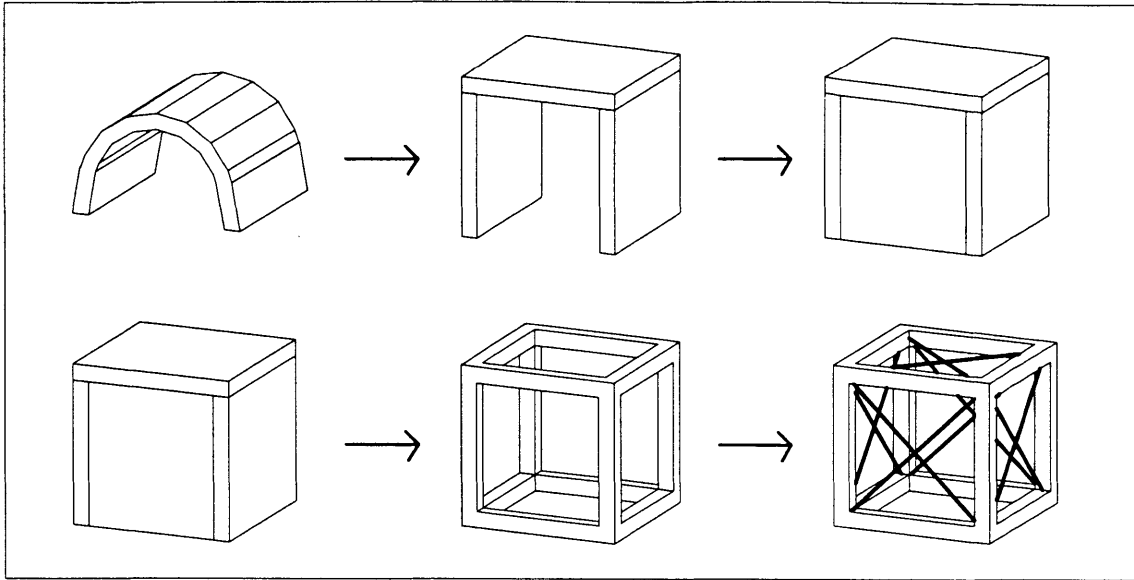


Figure 3-12: The structural transformation of a shell scheme into a box scheme into a frame scheme

earliest American proponents, and a metaphysical statement relating to a Cartesian ordering of the cosmos by its European proponents,⁵ the frame has been the industrial recipient of the same lofty status enjoyed by the masonry arch and vault from pre-history to the mid eighteenth century.

An abstract structural transformation of the generic scheme types from shell to box to frame is depicted in figure 3-12. Assume, for the purposes of this illustration, that the material used for all of these schemes is the same: some type of homogeneous plastic, for instance. Assume also that the material thicknesses used are all identical. We can now compare the inherent statical abilities of each of these schemes in terms of a fictional (but illustrative) *evolution* of their forms.

The catenary barrel vault shown (top left image) represents a true shell structural scheme. It is, by virtue of its very geometry, a highly stable and strong construction, exhibiting good resistance to vertical and lateral loads, horizontal shear, and torsion. Bending of the structure is not a significant problem since characteristic of the arch's geometry is the resolution of all evenly distributed, external forces to ones of internal shear and compression. This shell scheme will serve as a base case.

⁵[23]

In the simplest geometric abstraction of the vault described above, the panel components of the box structural scheme come together in the form of a spanning top member supported by two parallel walls below. The resulting scheme (top middle image in figure 3-12), although successfully defining an interior spatial volume, is not nearly as stable as was the vault. Not only is the form highly susceptible to racking failure under lateral loads in the direction normal to its side walls (causing it to “fold-up” like a house-of-cards), as well the top member is compelled to resist vertical loads in bending across one of its weakest axes (on the flat rather than parallel to its broad dimension). This will cause inevitable deflection (or sagging) in the middle.

To remedy the structural problems inherent in this “primitive” version of the box scheme, one need only insert the third and fourth wall panels, forming a box fully enclosed on all sides (see top right image in figure 3-12). These additional components, changing the geometry of the scheme but little, promise to dramatically improve its static performance, even if they are only pinned together. The four orthogonal wall panels now provide continuous vertical support along the perimeter of the top, roof panel while efficiently resisting all lateral and torsional forces by engaging those panels parallel to the applied forces in shear about their strongest axis. Since the roof panel acts as a two-way slab rather than a one-way slab, its maximum bending moments are significantly reduced (by about 25 – 35% depending on how it is attached to the tops of the walls).⁶

Now suppose that the box scheme just described (depicted again at the bottom left in figure 3-12) is transformed into a frame structural scheme (bottom center image in figure 3-12). Most dramatic in this change is the shedding of a great deal of material as the frame structure has become like a light and transparent, “minimal” version of the box scheme. Inherent in the frame’s geometry, however, are all of the static deficiencies of the early box scheme, each one now exacerbated. The primitive frame is weak in resisting lateral loads. It has a tendency to fold up in the same way that the primitive box scheme did, except now in *any* direction. A further disadvantage of the frame is its weakness under torsional stresses. Under an asymmetrical pattern of

⁶[15, p. 159]

lateral loading, the four top beams will tend to rotate with respect to the original floor plan of the scheme. When this happens, the columns begin to lean out away from their normal vertical positions, aggravating the condition of eccentric load transfer from above into the ground.

The simplest solution to the frame's structural problems involves the addition of cross bracing members between the ends of the columns and beams (see lower right image in figure 3-12). While still relying on the beam and column members in bending if they are loaded mid-span, loads applied at the corners of the structure are distributed through the members as purely axial stress. The frame now works as a large, three-dimensional truss or, as it is technically called, a *braced frame*. Its geometry is inherently stable, exhibiting all of the good statical characteristics of the vault. Figure 3-13 illustrates two alternative methods of stiffening a frame structural scheme. One involves the solidification of two of its adjacent sides with infill panels or "shear walls" (center image) and the other uses cladding elements as shear resistors, braced back into the frame at right angles to its flat surface (right image). These strategies are variations on the principles of schematic structural integrity through geometrical manipulation described above. Stiffening the connectors between each beam and column in the frame, resulting in a "rigid frame" or "moment resisting frame" is also possible. The difficulty in rigid frames lies in the critical nature of their joints, and in the significant bending moments induced within the frame members themselves near the joints. Rigid frames are inherently less efficient than shear walls or diagonal bracing.

Given the equivalency in material type, the pure vault is still much stronger than the braced frame overall, but considering the material quantities used, the significantly lighter braced frame is a more efficient structure. It has the additional benefits of easy expandability and assembly. Also interesting is the fact that the infill or shear panel strategy of frame stabilization, when compared in terms of material quantity used to do the same net structural work, is more efficient than the braced frame (about 35% more efficient).⁷ This is because loads distributed through planar members parallel

⁷Professor William LeMessurier class lecture: Building Structural Systems, October 8, 1993,

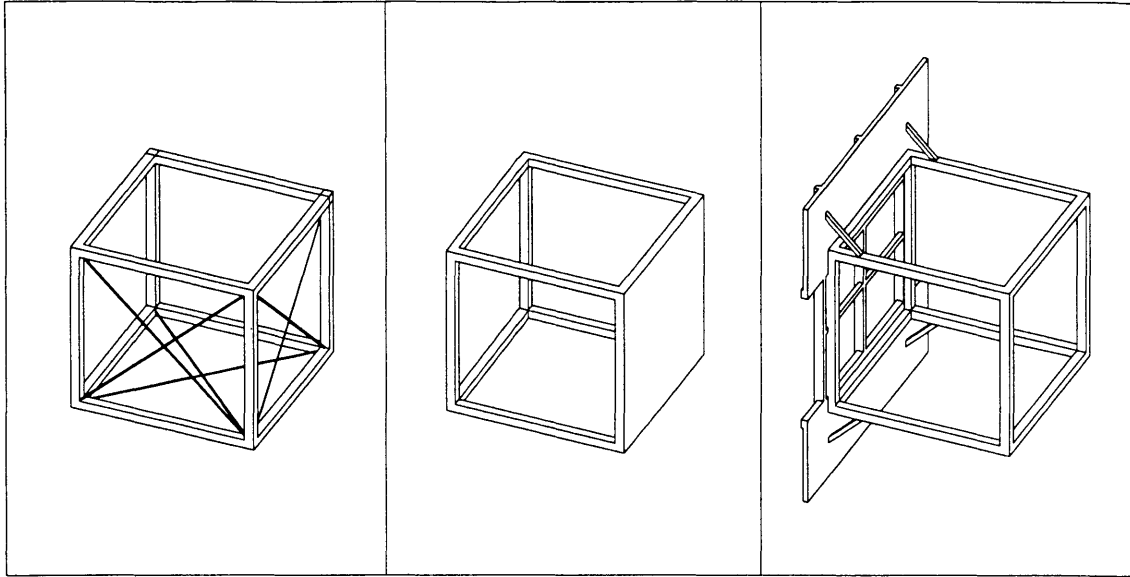


Figure 3-13: Three methods of stiffening rectilinear frame structural schemes, all of which involve the engagement of element members additional to those of the frame itself: (from left to right) diagonal bracing, solid shear wall, structural cladding –so braced to engage in diaphragm action

to the flat surfaces have much more material to engage in resistance than if they were routed through linear members, whose area of material resistance is limited by the least cross sectional area of the diagonal (perpendicular to its long axis). Given this reasoning, the high efficiency achieved in thin shell concrete structures (like those advanced by Felix Candela in the 1950's) is understandable. These structures rely on a specific schematic geometry in order to load very thin planar members most efficiently: co-planar to their broad surfaces as much as possible.

The frame scheme with infill “shear” panel has an additional advantage in the frame members themselves which, if made of a strong or reinforced material, act as boundary “flanges” around the perimeter of what now can be a very thin panel – even a sheet of fabric. Cut in plan-section, this configuration begins to resemble the standard section of a wideflange beam element. Not only does the frame and thin infill panel look like the section of a wideflange beam, it also behaves structurally in much the same manner.

When material type is considered, the issue of structural form takes on yet another

dimension. The braced frame, for example, simple could not be made in brick alone. It would not stand. The massive geometry of the vault, on the other hand, does not lend itself to construction in solid steel. In most cases, where the logic of efficiency has been consulted (i.e., where a sensibility toward the inherent efficiency of the structure has been consulted) we find that decisions of schematic form have been informed by a combination of issues including material type, speed and ease of erection (often referred to as *constructability*), internal spatial requirements, initial and long term costs, and modularity of the scheme (its basic spanning dimensions and ability to repeat itself horizontally and vertically).

How do the individual elements of a building structure undertake the task of resisting loads in tension, compression, and bending? Like schemes, their statical capabilities are very much influenced by the characteristic shapes that they take. The simplest form that an element can assume is that of a conceptually “point-like” solid, a “block” or “chunk” of material. Capable of resisting loads primarily in compression, these elements are usually held within a dense matrix of similar objects all working together. Linear shaped elements like posts or steel pipes lend themselves to the effective resistance of compressive loads as well but, due to the danger of their buckling under even slightly eccentric loads, are even more efficient in tension, where they can sometimes be greatly reduced in cross section, tending in shape toward that of a rope or cable (see image 1 figure 3-14). Linear elements are, by virtue of their material geometry, not very effective in resisting forces applied normal to their long axis (see image 2 of figure 3-14). Increasing the depth of a linear member greatly enhances its ability to resist loads in bending parallel to that depth. Elements possessing a planar shape, therefore, tend to perform best in bending and/or shear in a direction parallel to their broad faces (see image 3 of figure 3-14) and can be further optimized by exaggerating the amount of load resistive material placed along their long outer edges, as tension and compression flanges, leaving the material in the center as a web to resist shear generated in the coupling action of the flanges (see image 4 of figure 3-14). In bending resistance, sectional depth is a member’s most valuable asset since strength in bending is proportional to its depth squared.

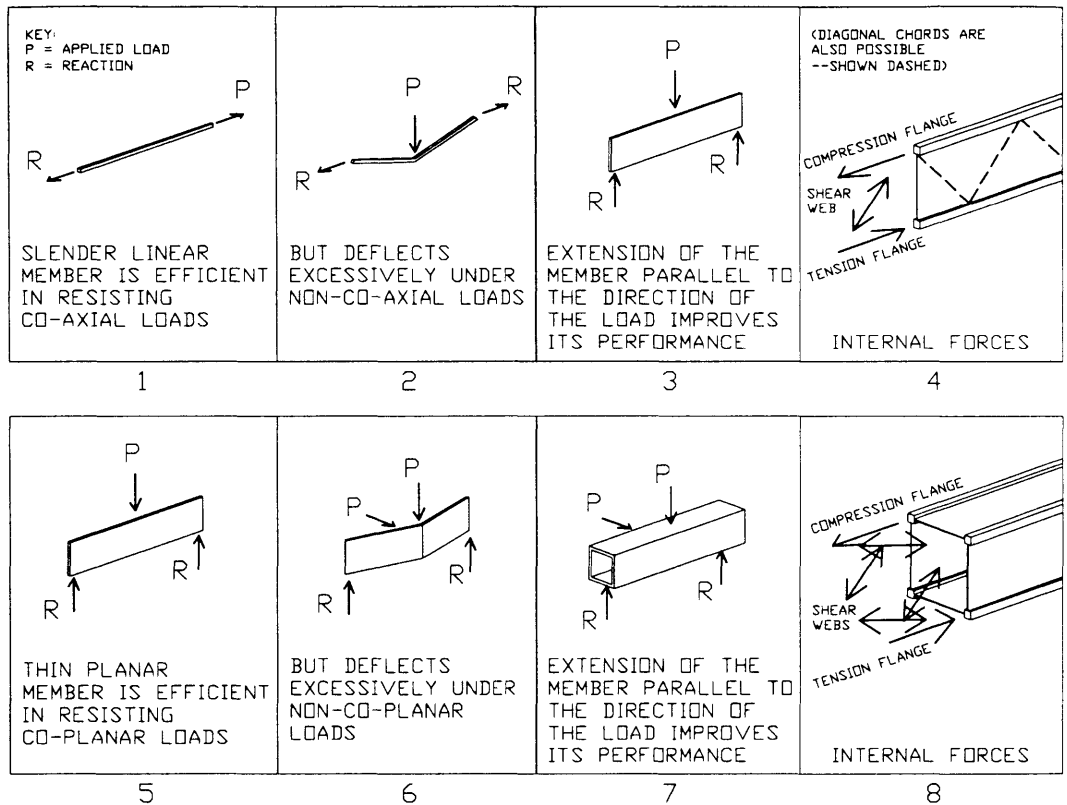


Figure 3-14: The effective resistance of bending forces requires an appropriate adjustment of member material disposition

Of course the broadening of the linear element along its depth to help resist bending loads still leaves an inherent weakness against laterally applied forces. The planar element tends to fold when it is loaded normal to its broad face (see image 6 of figure 3-14). Images 7 and 8 of figure 3-14 show the appropriate transformation of the shape of the planar member into a box and then a frame, respectively, as it is called upon to resist loads applied along all three of its cardinal axes.

The provision of habitable, volumetric space is the most critical role of building structural schemes. In most cases this requirement implies the spanning of open space and the engagement of materials in bending. In no other structural action is the geometry of material disposition within members more important than in bending action. The effective resistance of any anticipated force on a structural, spanning member depends on its ability to engage its own, internal moment arm, transforming the bending force into a balanced couple of tension and compression stresses (see figure 3-14). If a single load is applied to the member (at mid-span, for example), then the shear generated in this couple will remain constant regardless of the length of its span. Its tension and compression flange stresses, however, will increase proportionally to the length of the member's span. Since in most spanning applications it is desirable to maximize the length of the spanning members, the problem of high extreme fiber (flange) bending stresses is generally more critical than that of excessive shear. The serviceability of "beamed" structures is also directly related to the performance of their members in bending.

It matters little if the load-resisting geometry is a beam component or a habitable scheme itself (the tube-like assembly shown in image 8 of figure 3-14 could be either an element, like a box beam, or a scheme, like a rigid frame). The principle holds regardless of the scale of its application.⁸ Thus, as shown in figure 3-15, the global bending/spanning tasks of a building structural scheme may be taken up within a series of closely-spaced, beam-like elements (at left) or within the volume of the scheme as a whole (right image). Structural efficiency at the largest scale possible

⁸The limits of practical assembly, material strength and self-weight often dictate the practicality of the scale of application.

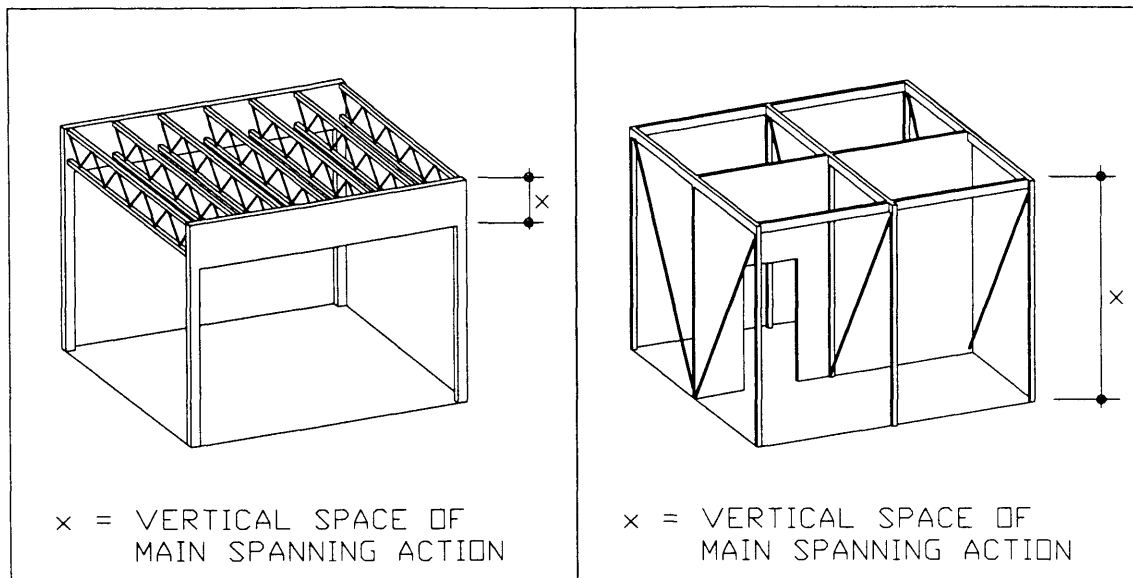


Figure 3-15: Two divergent attitudes taken toward the disposition of building structural elements and components within a structural scheme

is desirable since, the largest and most challenging spanning tasks are usually found at the level of overall structural scheme –i.e., on the level of a building’s habitable space. The larger the scheme, the more critical this efficiency is. The spanning of the structural scheme for an indoor sports arena, for example, is a much more demanding job than is that in an individual residence. Structural schemes with difficult spanning requirements must take maximum advantage of the space within which element and component members may extend themselves and, in their connected interaction, efficient schematic structural performance may be attained. In some cases, this space is interstitial and given over to the structure exclusively. In others the space of the overall schematic structural action and the habitable space of the building coincide completely (shown as the dimension “x” in figure 3-15).

As will be observed in the structure of the Back Bay rowhouse, a frequently used strategy for the strengthening of a flat, planar component in its lateral direction is to engage its internal elements in bending about their strong axes. In this way, the strength of its many constituent elements, on a *microscopic* scale, can compensate for an inherent *macroscopic* weaknesses in the component’s geometry (the arrangement of studs and plywood sheathing in 2x4 wood frame construction is a good exam-

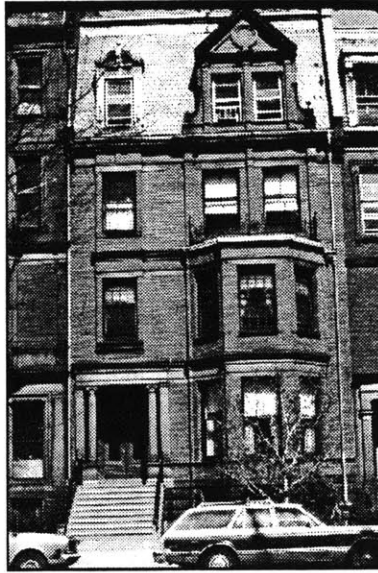


Figure 3-16: A rowhouse in Boston's Back Bay

ple of this phenomenon). The dialectic interplay between varying scales of material morphology from the level of the smallest element to the structural scheme, being variously *macro* and *microcosmic*, is critical to the effective systematic and organic behavior of buildings in general.

The Example of the Back Bay Rowhouse

The brick rowhouse type of Boston's Back Bay and South End is a good example of a building structural subsystem whose subordinate parts fall within the framework of a unified structural scheme (see figure 3-16).⁹ Built primarily in the late nineteenth century, this building type incorporates aspects of an increasingly mechanized building industry while, at the same time, exhibiting many characteristics of traditional craftsmanship.

The Back Bay rowhouse is composed primarily of the simple elements, bricks and wood boards. But they are completely subservient to their particular arrangement in larger component parts. For the rowhouse these larger components are the building's

⁹I am indebted to Professor Ken Kruckemeyer for his assistance in understanding the structural principles of the rowhouse and to Professor Eric Dluhosch for introducing me to its "tectonic" aspects.

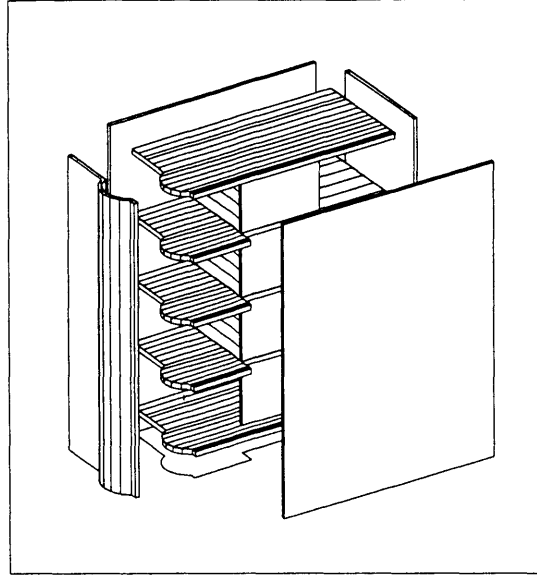


Figure 3-17: Exploded view of the major components of the Back Bay rowhouse

bearing walls and its floors and roof (see figure 3-17). The bricks are laid up around the entire perimeter of the building and over its full height in four large panel components. These can be seen to form a tube-like shell. Adjacent rowhouses typically share a common party wall between them, thereby extending an interdependent linking of shell components potentially across multiple houses, strengthening the system's coherence even over an entire city block.

The floor assemblies are comprised of the elements wooden joists and planking and are carried by the two exterior sidewalls in a continuous span (about 20') across the width of the building. Where a floor opening is made for the communication of stairs, elevators, etc, an additional interior bearing wall (or possibly a trabeated component) is provided to "detour" the floor loads thereby interrupted. Combining members of the component groups—exterior bearing walls, interior bearing walls, floors, and roof—we arrive at the scheme of the row house. It is a box type building structural scheme (see figure 3-18).

From the exploded axonometric drawing of the rowhouse shown in figure 3-17, one gets a sense of the proportions of the wall components themselves. The side walls, for example look like thin sheets of cardboard, yet they are drawn to correct scale in the figure. In fact, their actual dimensions are about 45' high, by 40' wide, by only

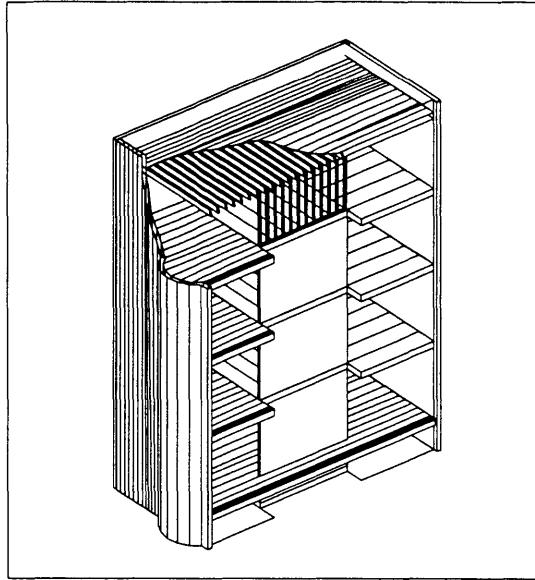


Figure 3-18: Cutaway view of the rowhouse as a box scheme with its elements and components

8" *thick!* Anyone who has played with toy blocks before knows that such a wall will tumble with the first floor vibration or gentle breeze that blows on it. In technical terms it will either fail in *buckling*, when the wall's lateral deflection causes its vertical loads to become increasingly eccentric to the perfect vertical axis of the wall, or it will simply tip over in one piece due to excessive lateral loads. Figure 3-19 illustrates both of these modes of wall failure. The dimensions labelled "e" in the figure refer to the eccentricity of the load being applied.

The solid brick masonry wall shell of the traditional Back Bay rowhouse serves the multiple statical functions of horizontal support of the floors and roof, resistance to wind load, security of the occupants and their belongings, and thermal and moisture protection of the building's inside from the elements on the outside. The bricks themselves, however, are not designed for the optimization of any of these functions. They are small, brittle, hygroscopic, and rather poor in sound and thermal insulation. And yet the rowhouses made with them are standing, as solid as ever, one hundred years after they were built.

The stability of the Back Bay rowhouse structural subsystem is explained not by the characteristics of its elements taken singly, nor by the abilities of one of its

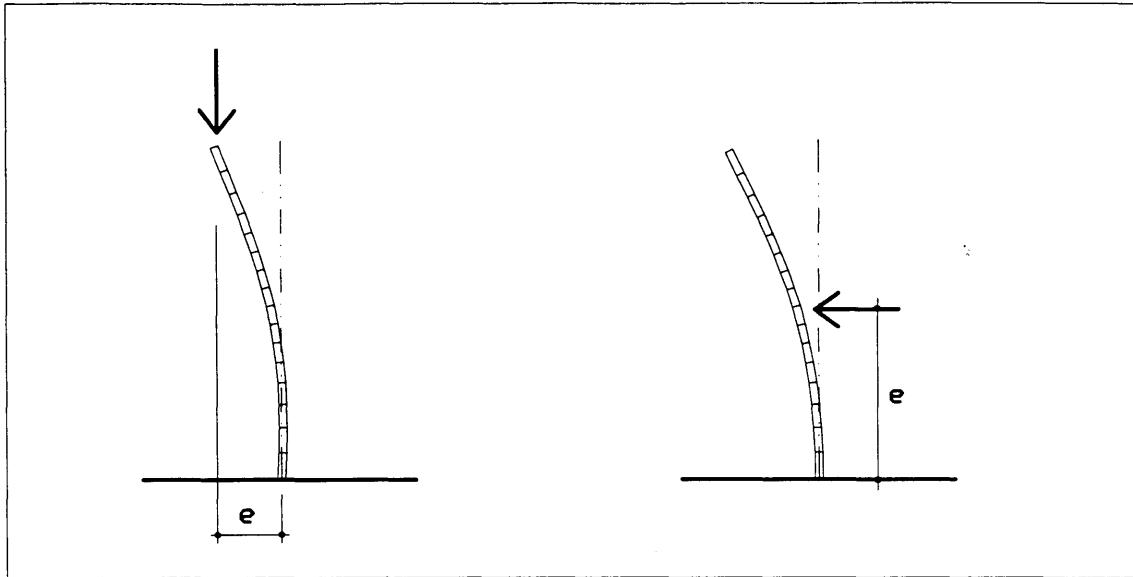


Figure 3-19: Vertical wall failure by means of buckling (left) and lateral force (right) components viewed in isolation. Rather its strength lies in the combination of all of these parts acting as a system.

Because the bricks are interlocked within a bonding pattern that incorporates about 80% of their total surface area in full mortar contact, the brick wall can assume a behavior that is both massive and solid. It is also remarkably flexible considering the brittle nature of the raw materials used in its making. Especially due to the soft, lime mortars that were commonly used in the nineteenth century, loads applied to one point at the top of the wall are not carried to the ground along a single line of highly concentrated pressure but, consistent with the overall geometry of the wall, are distributed throughout its network of joints in the form of an expanding cone (at about 45 degrees) and evenly transferred to the foundation below (see figure 3-20). Local imperfections in the brick or in their bonding pattern are forgiven by the wall's distribution of stresses over large areas. Redundancy in the overall fabric of the wall renders it statically conservative in compression.

The brick wall still exhibits a weakness toward loads applied normal to its broad surface, though. Note in figure 3-19 that, based on the relative moment arm generated in the wall's resistance to eccentric vertical loads versus that from purely horizontal forces, the wall has to work much harder to support itself as a vertical cantilever than

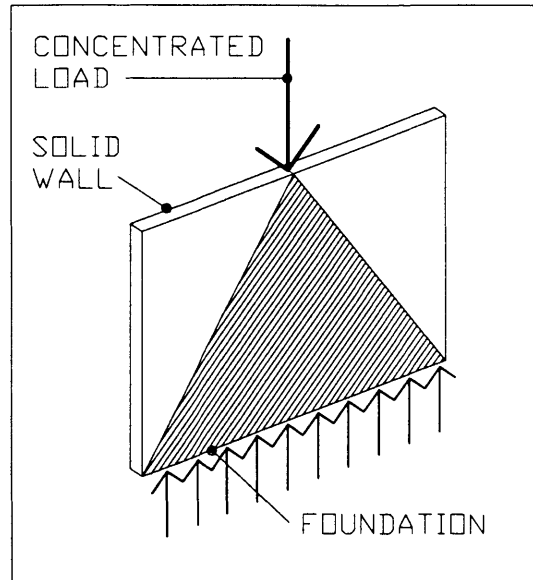


Figure 3-20: Concentrated loads applied at the top of a brick wall are distributed throughout its network of mortar joints in a triangular pattern at about 45°

it does as an “imperfect” axial member. This is not simply a result of the masonry material’s inherent lack of strength in tension and bending. More importantly, it is a characteristic of the broad, planar geometry of the wall component itself. The interconnected form of the whole wall shell responds to this shortcoming by engaging its two walls parallel to the direction of the applied lateral forces in shear resistance along their strong axis (see the left image in figure 3-21).

Now the difficulty becomes one of safely transferring loads received on the broad face of the wall to its edges where support from adjacent, “shear” walls can be procured. Because the floor plates are also situated with their strong axes parallel to the direction of any applied lateral forces, they, too, can act in support of the wall. The floor plate components (and the roof component) assist in the support of the overall building structure by transferring lateral loads to the parallel wall components where they can be engaged as shear planes. The floor and roof plates also prevent the racking deformation of the masonry wall shell in plan by maintaining their rigid rectangular geometry even under asymmetrical or unequal lateral loads (see figure 3-21, right image).

In a “textbook” example of systems behavior, the floor plates of the Back Bay

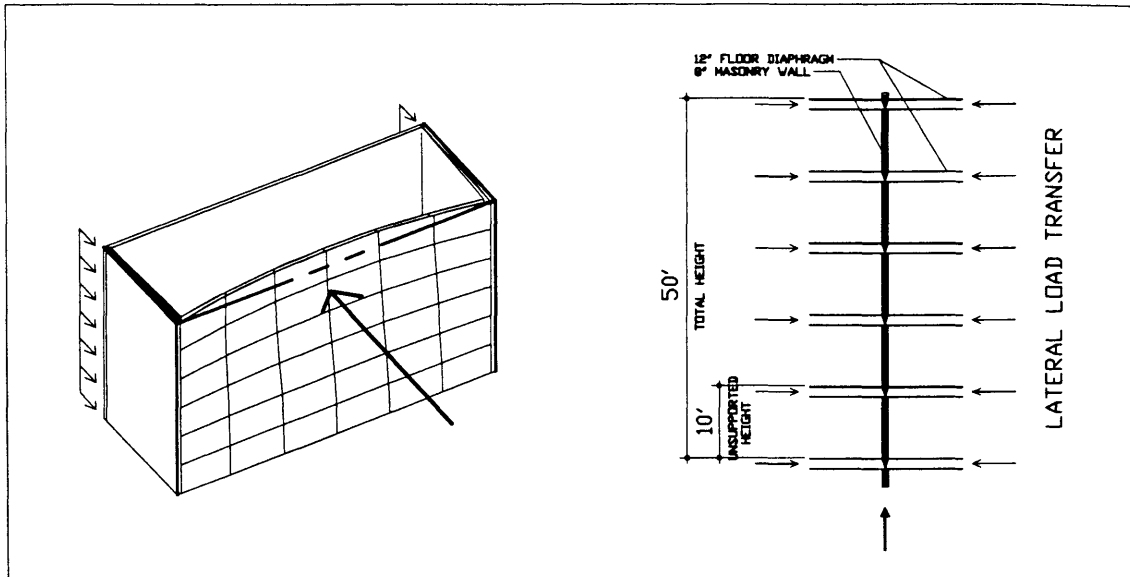


Figure 3-21: Walls parallel to applied lateral forces act as shear planes while effective bracing of the “thin” masonry party walls is provided by the floor plates which act as horizontal diaphragms

rowhouse are dependent on the masonry walls which bound them for their vertical support while, at the same time, they support these same walls by providing resistance to deformation under lateral loading.

Of course, the condition of interdependence between the parts of the rowhouse scheme described above occurs only if each component can effectively contribute to the statical integrity of the larger scheme. It assumes, for example that the floor plates can self-sufficiently maintain a strict rectangular geometry in plan while avoiding excessive sagging under gravity loads. It assumes that in the bonding pattern of the exterior brick masonry walls there is enough internal cohesion to generate the resistance required of them as shear walls. (This ability can be severely hampered by the presence of large window openings in the front and rear walls of the rowhouse.) To understand how these imperatives are achieved we need only shift the focus of our inquiry from the schematic level to that of the components themselves, wherein the forms of their own internal, constituent parts can be observed.

Figure 3-22 shows the elements of the floor component in the context of the traditional Back Bay Rowhouse: 2x10 wood joists, 1” thick wood planking, short wood

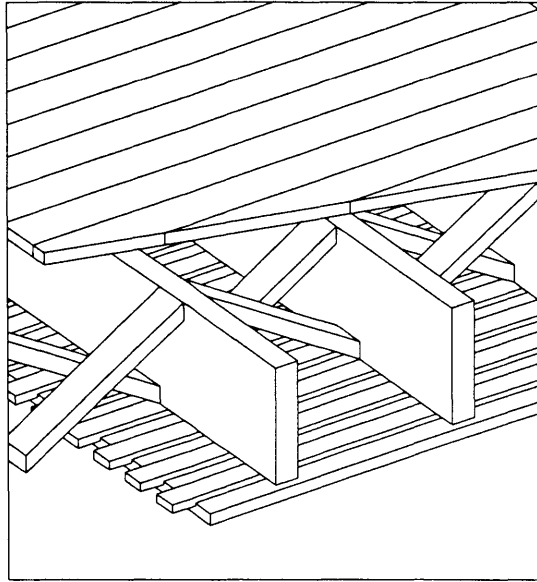


Figure 3-22: Elements of a floor component

cross bridging, and wood lath and plaster. None of the parts shown is single-handedly capable of doing the work of the floor plate as a whole and yet, working together, they carry out its tasks in a highly efficient manner. The floor is made from readily available materials and is easy to assemble on site. The fact that contemporary wood framed floor construction differs little from this traditional standard is a testament to its genius. The most significant change has been the substitution of plywood decking for individual planks and gypsum board for lath and plaster.

The placement of the wood joists on edge engages them in their strongest sectional dimension while their weakness in the lateral direction (their tendency to flip over onto their sides under heavy vertical loading) is compensated for by the planar strength of the decking securely nailed on top, and the lath and plaster ceiling similarly bracing the bottom edges of the joists. Most remarkable in this assembly is the use of relatively thin, rib-like joist members as miniature beams embedded within a component whose overall geometry suggests nothing of the sort. The shape of the floor plate suggests a solid slab of homogenous material, like that of the masonry walls. Were this latter to be the case, however, the floor would suffer from its own great self-weight as much as it would profit from an only moderate increase in strength. The cost in terms of material waste would be similarly irrational. As utilized in the rowhouse structural

scheme, the inherent strength of the joists cooperates with the inherent strength of the decking and soffit in order to produce a combined assembly which uses a minimum amount of material (and thus self-weight) for a maximum statical strength. Like the scheme transformation example that was given earlier in this section, the brute strength and stiffness lost in a paring away of much of the mass of a component, leaving mostly space and a minimum of material pushed to its most effective statical disposition, is more than made up for in the increased efficiency of the structure as a whole.

A further interactive aspect of the element parts in the rowhouse's wood framed floor is their ability to distribute vertical floor load throughout a number of the nearby joists, preventing the need for one member to bear all of the weight of a concentrated load applied directly above it. Like the "matrixing" of brick elements in the masonry wall shell, the close spacing (16" on-center) and frequent connections between joists in the floor component establishes a redundancy that allows the responsibilities of individual members to be down-played in favor of the communal action of many. But the most important players in the sharing of loads between adjacent joists are the diagonal bridges lined up in rows between them (at approximately the third points along the joist spans). Diagonal bridges triangulate the structure of the floor sandwich in section so that, by acting as compression chords in the spaces between joists, some of the forces incurred in one joist are spread to others (see figure 3-22).

Exhibited in the repetition of the joists of the floor diaphragm and the bricks in the masonry tube, for example, redundancy of interlinked elements is the cause of two related results. One is that individual members can be downsized since there are more of them to disseminate loads. The wall need only be eight inches thick while the floor diaphragms require a similarly thin dimension. Smaller individual element sizes and more interconnecting joints between them forming larger components means that the component will be more flexible and can "give" rather than fail, as would an individual, isolated, rigid element. The other result is that more frequent, closely spaced members acting in concert can more easily distribute between each other concentrated loads that may occur near one of the members. Much larger concentrated

loads than that which a single, isolated such member could handle are easily accommodated by the systematic “load sharing” reaction of the whole component as is seen in the translation of concentrated floor loads through the floor planking and diagonal bridging and ceiling lath and plaster to adjacent joists. Overstressing and excessive deflection of a single element are thus avoided. Structural schemes whose components are comprised of networks of many simple elements often contain an intricacy of multiple, interconnected load paths which are capable of sharing loads internally according to the capabilities of each path automatically without a critical dependence on any single one.

Organic character in the rowhouse building at the level of its overall structural scheme is evidenced by the interdependent functioning of its main components. The mutually interactive support that they incur is, in turn, predicated by their own inter-element dialogues. These are the very essence of the “conversation” between parts. An investigation of the organic character of the rowhouse example affirms the contention that was made in chapter 1 of this thesis, –that only in concept is the separation of material shape and structural behavior meaningful. In real material things these two are intimately related and integral. The next section of this chapter explores three further aspects of the systematic nature of buildings and their parts, supporting the notion of a unity of form.

3.4 Systematic Aspects of Components and Elements

3.4.1 The Phenomenon of Component Nesting

The division of a building’s structural subsystem into schemes, components, and elements is clear at the level of its major pieces: its walls, floors, roof, and their elemental members, bricks, joists, planks, plaster, etc. But in the experience of architecture, especially in traditional construction like that of the Back Bay rowhouse, there appear to be many more layers of articulation of these major components than

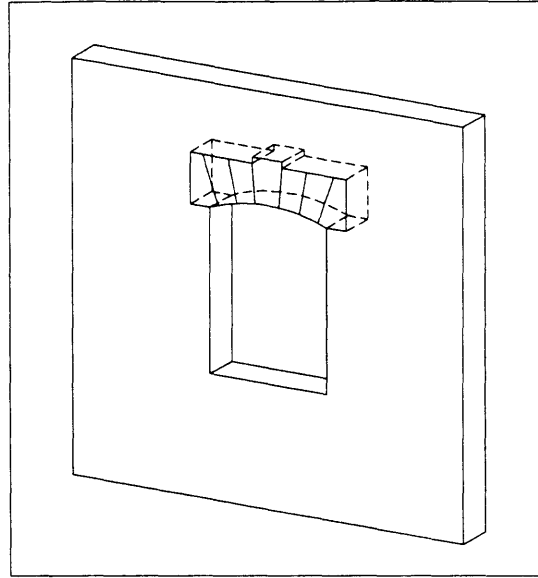


Figure 3-23: The lintel *within* the wall poses a potential ambiguity between what are elements and what are components

can be accounted for by combinations of element parts alone. Indeed, if one considers the spanning of wall openings by simple masonry lintels, some confusion may arise as to whether the lintel member is an *element* of the wall or a *component* unto itself (see figure 3-23). In the sense that it is a part of the component, wall, it must be an element. At the same time it can justifiably be argued that the lintel is a component. It is a “designed” assembly which is made out of element parts, performing a distinct role in the service of the larger building system, unique from those parts immediately around it. The lintel is, in fact, a component for just these reasons. But it is a different kind of component from the wall panel in which it is situated.

This is not an unusual arrangement of parts. In fact, there are many examples of this kind of interplay between variously scaled and interconnected component members in the structural scheme of the Back Bay rowhouse alone. The phenomenon at work here is called the *nesting* of components. An investigation of component nesting involves a more refined hierarchical breakdown of component parts within a subsystem, in the recognition that some components occur *within* others. The logic of nested components requires that, while distinct as component parts in and of themselves, nested components also contribute in some direct way to the morphology of

their immediate parent: another component.

Nested components must enhance the form of the overall building. But they do not always do so *vis-à-vis* its structural subsystem specifically. Though a window opening may not directly enhance the statical performance of the wall in which it is cut, it does provide a valuable service to the interior environment of a building. Some nested components, however, like the curved, projecting brick bay of the Back Bay rowhouse, do contribute to the structural strength of the building while also serving the visual articulation of its habitable space.

In establishing the precise hierarchy of nested component levels within a particular building one must begin at the highest component level and identify the subordinate layers of nesting within it respectively. In the rowhouse example we may begin by calling the masonry *wallshell* itself (the boundary walls of the building) a *level 1 component*. The masonry wall is composed of a series of *level 2 components*, integrally linked to each other at their corners. These are the *front facade*, *sidewalls*, and *rear wall*.

Level 1 and level 2 components were the subjects of the preceding investigation of the overall statical behavior of the building structural scheme. Such upper-level component analysis becomes even more critical as the size and complexity of the building increases. A closer look at the front facade of the rowhouse reveals that much of its articulation occurs at lower levels, nested within these larger parts.

Figure 3-24 shows the front facade of the building in more detail. It bears a number of recognizable parts inferior to itself but contributing to its overall form. *Level 3 components* in this building type include such major wall articulations as porticoes, entablatures, ornamental panels, plinths, pediments, lean-to's, chimneys, buttresses, apses, and turrets. Within these can be found a fourth level of component subdivision. *Level 4 components* may in this case consist of window and door frames, engaged columns and pilasters, steps and railings, cornices, thresholds, arches, brackets, quoins, band courses, friezes, lintels, sills and jambs (see figure 3-25). Finally in figure 3-26 we have a representation of the basic elements, wood and glass, which combine to make one *level 4 component*, a custom-made window.

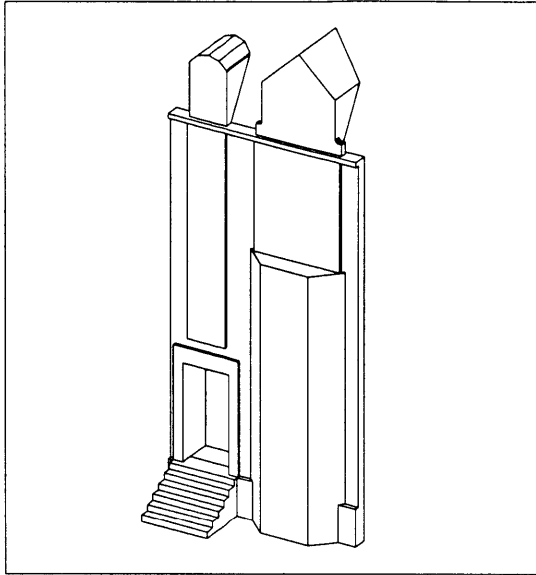


Figure 3-24: The level 2 component facade as a field in which are nested items from lower component levels



Figure 3-25: Level 3 and 4 components of the rowhouse facade

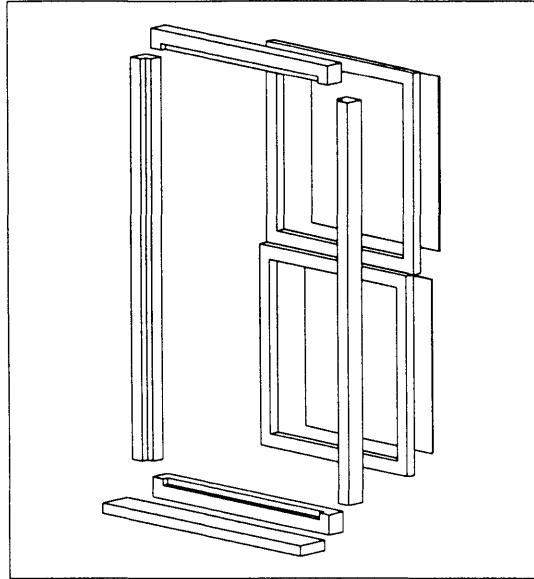


Figure 3-26: Elements of a (custom made) window component

Establishing levels of component parts nesting for a particular building does not in any way make those designations universal. Consider, for example that within some building structural subsystems there may exist only two or three levels. If the window described above had been an off-the-shelf, “stock” unit then it would have been considered as an element of construction and not a level 4 component. Some buildings, on the other hand, may involve the integration of many more levels than were attributed to the rowhouse facade. Altering the scale of a building component can change the level at which it is nested within the overall building. The two examples shown in figure 3-27 demonstrate the effects of both magnifying and shrinking the scale of a component. In the case of the lintel component in the wall shown in the upper left image, a magnification brings it up to the level of an entire wall, spanning what may be a storefront below (upper right image). A common example of the shrinking of a component is given in the lower images, where a classical portico moves from the status of an entire temple front to that of the entrance porch of a rowhouse building.

If one examines the distribution of the component parts of buildings in a comparative way, an indication of their relative *consistencies* (the evenness of the grading of their nested, constituent parts) should be obtained. The existence of many small

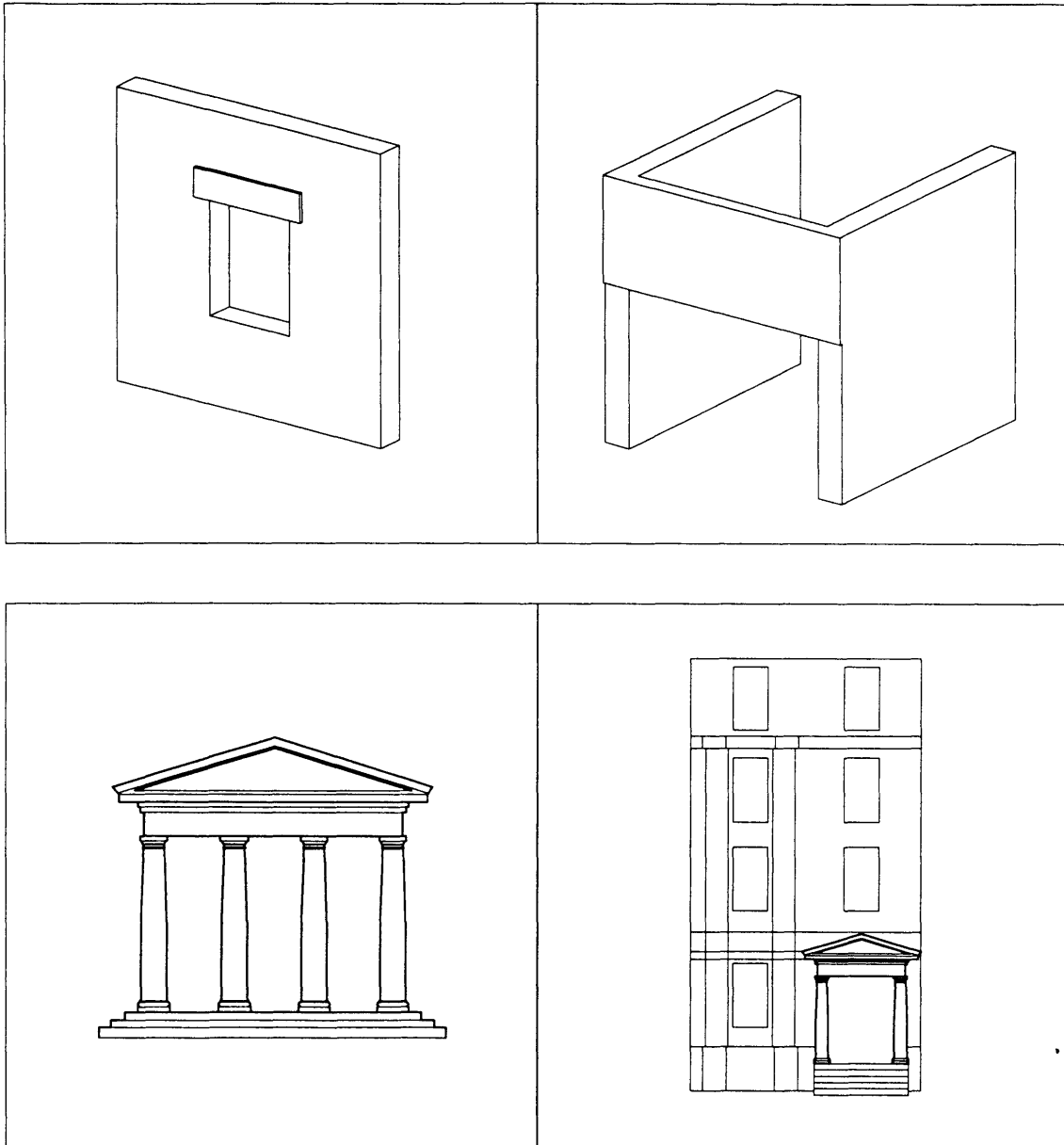


Figure 3-27: A change in component scale often involves a change in its nested *level*

parts at upper-component levels (those with low level numbers), for instance, is indicative of a higher contrast in scale between the parts of adjacent levels. Conversely, if the smallest components reside at very low component levels (those with high level numbers) then one would expect a very gradual change in scale between the parts of adjacent levels.

Building structural schemes which consist of very large, standardized, stock components (on the order of entire walls and floor slabs, for example) are likely to have very few subordinate component levels which are open to variation by the architect or builder. Such large, off-the-shelf items tend to come in only limited varieties due to the high relative cost of uniqueness versus homogeneity. More depth to the component nesting hierarchy in a custom building means that more attention has been paid by an architect or builder to the smooth and gradual transition within its scheme from the largest component parts to the smallest. It means that the building has been more “designed.”

In general, the physiognomical expression of a building and the articulation of nested levels of component and element parts is achieved in a number of ways:

- One common technique involves the variation of material type, surface color, and texture resulting in a visual contrast in their surface appearance. Nineteenth-century American architecture commonly nested light-colored limestone detailing into otherwise plain, dark brick facades. Good examples are seen in Boston’s Symphony Hall and Horticultural Society buildings on Massachusetts Avenue.
- Another approach is to resolve more complex (perhaps schematic) geometries through the articulation of simpler, and smaller, nested component parts. This is often apparent in the nested “grid” expressions given to the cladding of high-rise buildings, which could, in concept, be repeated *ad infinitum*.
- Yet another strategy uses the deliberate manipulation of the scale of parts so that smaller, nested pieces become at once details, subservient to their parent components and “microcosmic” wholes with their own very distinct, perhaps symbolic morphologies. This kind of architectonic treatment can be seen in

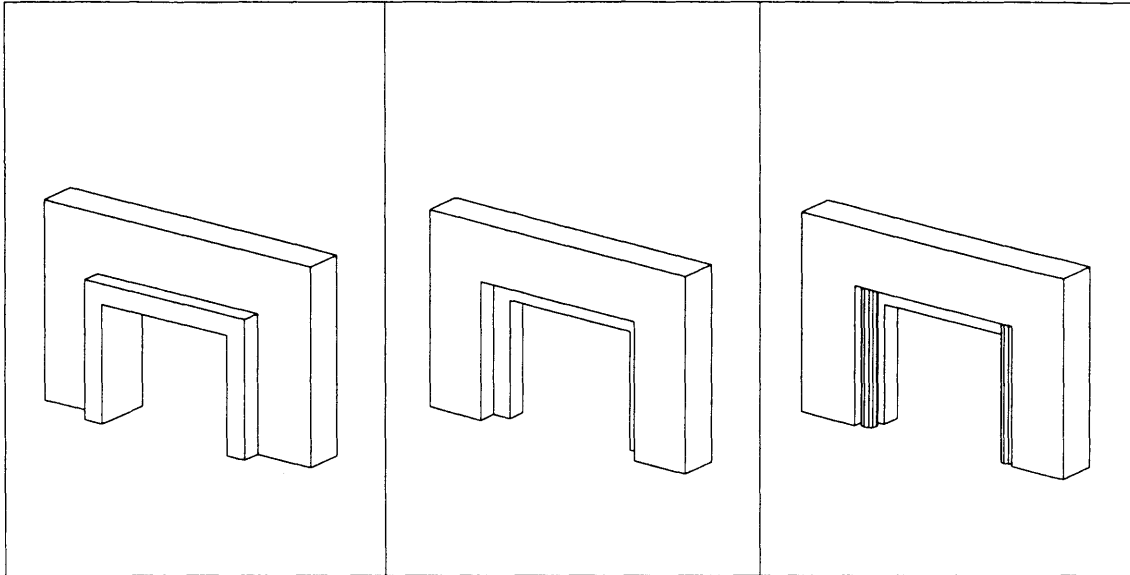


Figure 3-28: The interpretation of *additive* versus *subtractive*, nested component articulation

the richly sculptural facades of baroque architecture and very often in funerary architecture.

- Finally, there is the exploitation of the statical action of a building subsystem, through the purposeful handling of the parts' joints. This strategy begins to highlight, in the forms of nested, individual parts, their purposeful relatedness to the larger structural scheme by emphasizing the dimensions of the members themselves and the ways in which they are joined together. One is given a strong sense of the schematic principles of the John Hancock building in Chicago, for example, through the clear expression of member sizes and connections in its facades. The topic of parts jointing will be more fully explored in section 3.5 of this chapter.

Also important in the distinction of the hierarchy of building parts is the fact that nested components can take the form of either apparently additive or subtractive articulation, as is demonstrated in figure 3-28. The distinction between apparently additive (left image in figure 3-28) and subtractive (middle image) instances of nested component interaction can be an issue of disagreement, especially when a level of detail, achieved by any of the means listed above, suggests a combination of the two

(right image).

Manipulation of formal relationships with respect to the interaction of hierarchically differentiated, nested component parts is productive of many of the dialectical visual effects described in chapter 2, namely: phenomenal transparency, parralactic motion, occlusion, fragmentation, and expressed affordance of the objects apparent in an observer's dynamic, ambient optic array.

3.4.2 The Changing Natures of Building Elements

An interesting distinction between the traditional elements of building construction and those developed as part of its industrialization (over the last 200 years) is illustrated in figure 3-29. Note that the fabrication of traditional building components (the stone pedestal and the wood frame detail shown in the lower half of the figure) involves a transformation of elemental materials so common in their un-worked forms as to have little distinct value one from another. In the example shown, rough timbers and undressed stone must be individually cut, shaped, and fitted together before becoming recognizable as parts of buildings specifically. In the end, however, they become, highly crafted, one-of-a-kind building components.

Indeed since pre-industrial structural elements (e.g., bricks, logs, stone blocks) had little functional meaning outside of their systems context (before their transformation into walled, arched, vaulted and domed enclosures as structural schemes, for example) their development and improvement tended to be predicated on refinements made to the *systems* of which they were a part and not to them *per se*. Thus the solving of structural (really "con-structional") problems traditionally involved the manipulation of the geometry of the structural scheme (three dimensional space defining structural unit) as opposed to the refinement of individual elements or the substitution of one structural component for another possessing more desirable static capabilities. Viollet-le-Duc's research into medieval building methods revealed the critical nature of geometric order at the schematic level in twelfth and thirteenth-century French masonry construction. Figure 3-30 depicts Viollet-le-Duc's spatial, geometrical understanding of Gothic masonry vaulting. In the right image, the flying

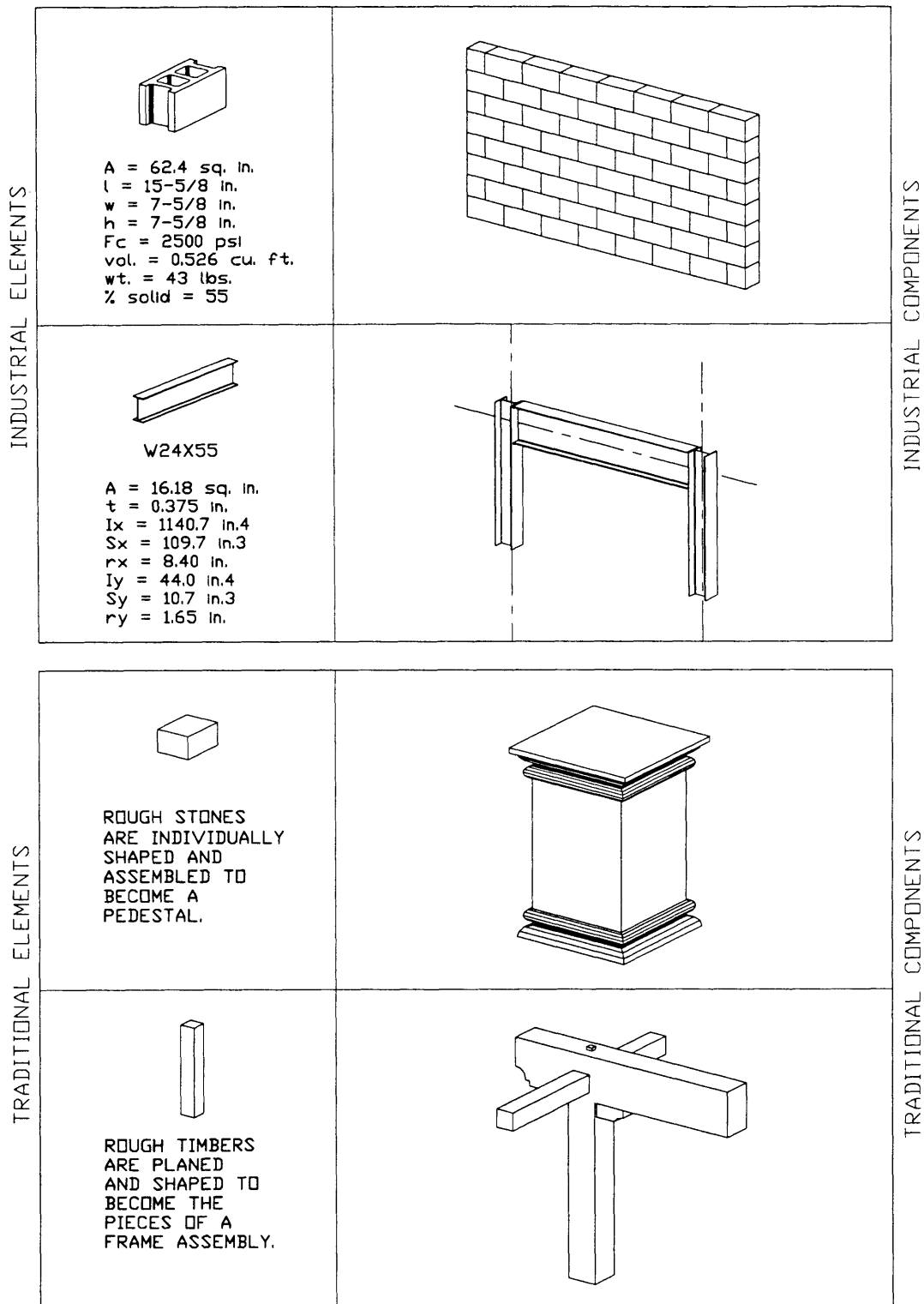


Figure 3-29: The highly specific natures of steel wide flange sections and “concrete masonry units” render them “generic” and somewhat anonymous in typical industrialized applications while the simple wood timber or stone block are traditionally transformed into artifacts of great specificity

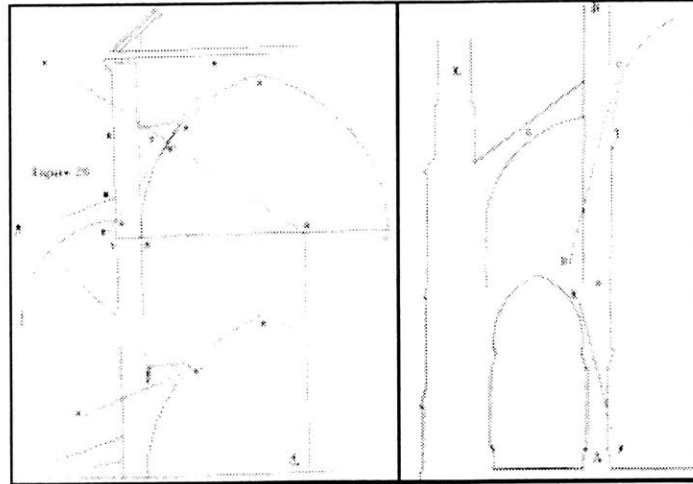


Figure 3-30: Viollet-le-Duc determined that the Medieval masons optimized the geometry of their structural schemes in order to optimize their size and stability. Shown are two analyses of the critical geometry of the pointed arch and its buttressing. (from Viollet-le-Duc's *Dictionnaire Raisonné*)

buttress is shown as a solution to the problem of cracking. The solution manipulates not the material used in construction but the geometrical principles of its disposition within an overarching, three-dimensional “system.”¹⁰

The “industrial” examples, however, undergo a radically different treatment. Already in their “raw” state they possess definitive and characteristic morphologies, ascribed to them as individual objects with known material properties. In fact, they have been optimized in and of themselves to perform in certain documented ways (some statical characteristics are listed beside each element in the illustration). Within the frame and wall components shown in figure 3-29, however, these elements take on an anonymity owing to their minimal transformation from mass-produced building elements to components. As parts of components they retain a strong sense of the individual, objective identity they had as elements, contrasting the unequivocal formal subordination of the traditional elements in larger assemblies. To make a broad generalization, the elements of industrial production can be used in quite generic fashion within their systems context where they are readily substituted and can be removed or reinstalled at will, still retaining their autonomy as objective parts

¹⁰[27]

in isolation. William Mitchell affirms these aspects of industrial parts in *The Logic of Architecture*.

Two components are functionally equivalent when they both adequately perform a specified role. For example, we can replace the wheel of a car by a functionally equivalent spare wheel or the lead in a mechanical pencil by another lead or the blade of a knife by another blade. The use of functionally equivalent interchangeable parts in this way has become one of the cornerstones of modern industrial production.¹¹

Besides “functional equivalency,” the development of modern building parts has another interesting aspect. In industrialized building parts production there is a strong tendency toward the dissection of what were once “compact” structural components into a sequence of smaller and more specialized element parts, each being assigned more specific statical tasks.

The efficiency of the floor plates in Back Bay rowhouses was greatly improved with the use of a set of functionally specific but interdependent element parts in its construction rather than a solid, prismatic mass of material. The resulting floor component was much lighter because it eliminated all solid material that could not be directly engaged toward some critical aspect of the form of the overall component. By employing the most efficient abilities of many, repetitively deployed element parts—be they in compression, tension, bending, shear resistance, or bracing—the statical performance of the floor was optimized. What we see in the development of industrialized building elements is nothing short of an extension of the concepts used in the optimization of the rowhouse floor components.

An example will serve to better illustrate the traditional approach versus a developing industrial approach to building structural systems. Consider the series of walls shown in figure 3-31. The rectangular prism at the top left represents a traditional, solid, load-bearing masonry wall. The others use metal frame and panel elements: unique products of the industrialization of building materials. The overall

¹¹[17, p. 210]

size and shape of these walls is the same and, likewise, all are responsible for the net provision of the same, multiple statical functions, including horizontal and vertical load resistance, thermal and moisture control, sound isolation and security, etc. The traditional masonry wall accommodates all of these functions through the monolithic repetition of its one structural element, the brick. Its density of interconnections makes for a solid and massive component. Although it may be true that none of the functions listed above are accomplished as efficiently as they might be were the wall designed to handle them separately (in isolation of each other), the use of the massive wall relieves its designer of having to consider each function separately (with the inevitable outcome that there will be a few issues left unaddressed). It provides a kind of “blanket” coverage for all of these issues. Thus the traditional masonry wall affords the accommodation of the statical functions of its larger building scheme seemingly automatically without explicit reference to the inherent complexity of its own internal workings.

The industrial strategy depicted in the top right image embodies a striving on the part of its designers to break these multiple functions down into the individually determinant statical actions of several parts internal to the wall’s overall geometry. To each of these internal elements can be assigned particular statical functions. The vertical ribs are responsible for the transmission of gravity loads into the foundation while the horizontal elements may be designed to resist all of the lateral loads exerted on the face of the wall in bending, converting them into shear forces in the adjacent side walls or columns of the building. the outer panel must, in turn, provide security and thermal and moisture protection to the interior of the building. When these smaller parts are combined, the wall will perform systematically, as the concerted whole predicted.

In the bottom left and right images of figure 3-31, individual elements have undergone further optimization, resulting in a proliferation of complicated element shapes made of many interdependent, specialized element “sub-parts.” I call this a process of *micro-optimization*.

Continuing the process of micro-optimization one can eventually conceive of a

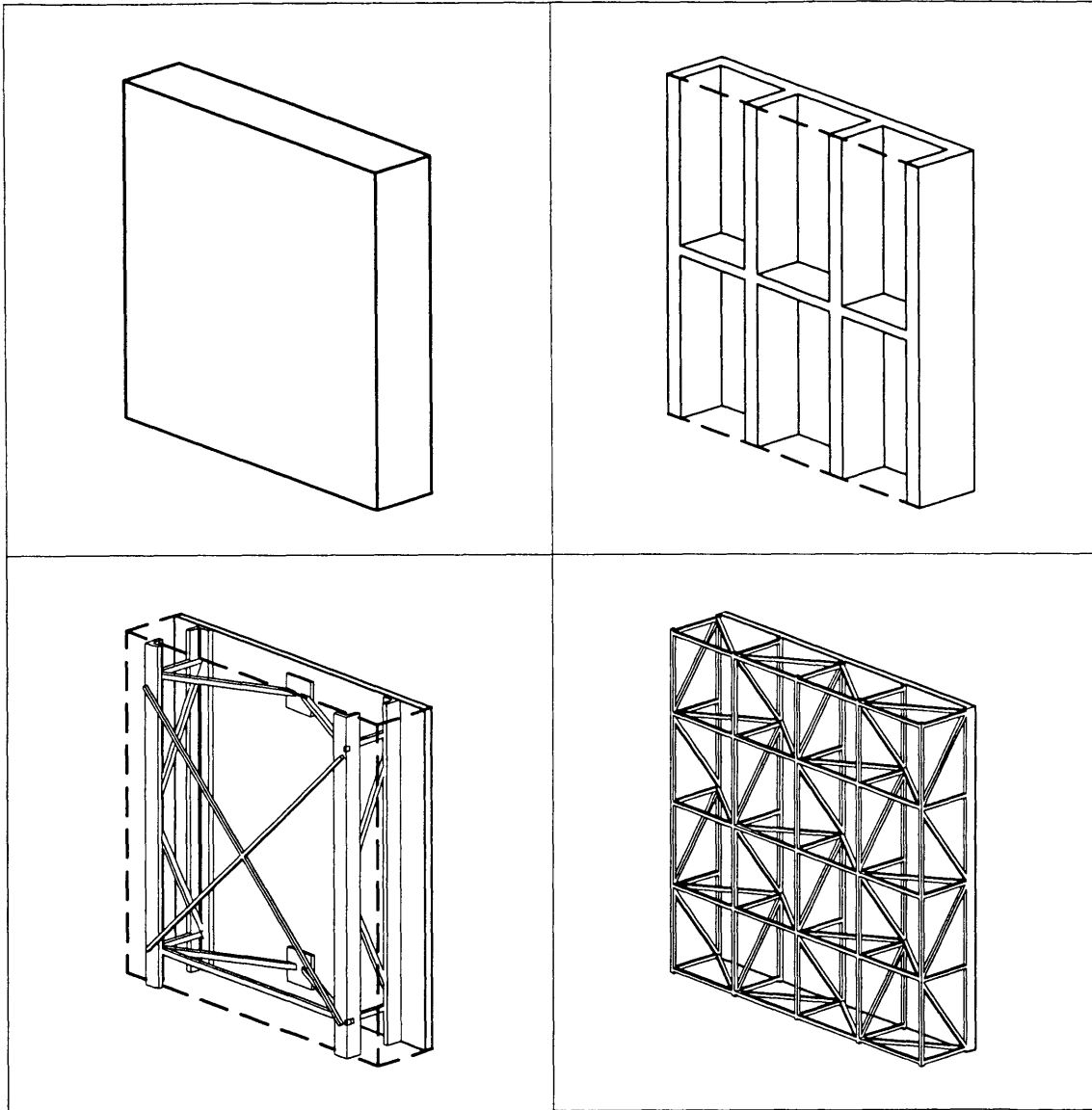


Figure 3-31: A traditional masonry wall (top left) as the precursor to a progressive process of element *micro-optimization*

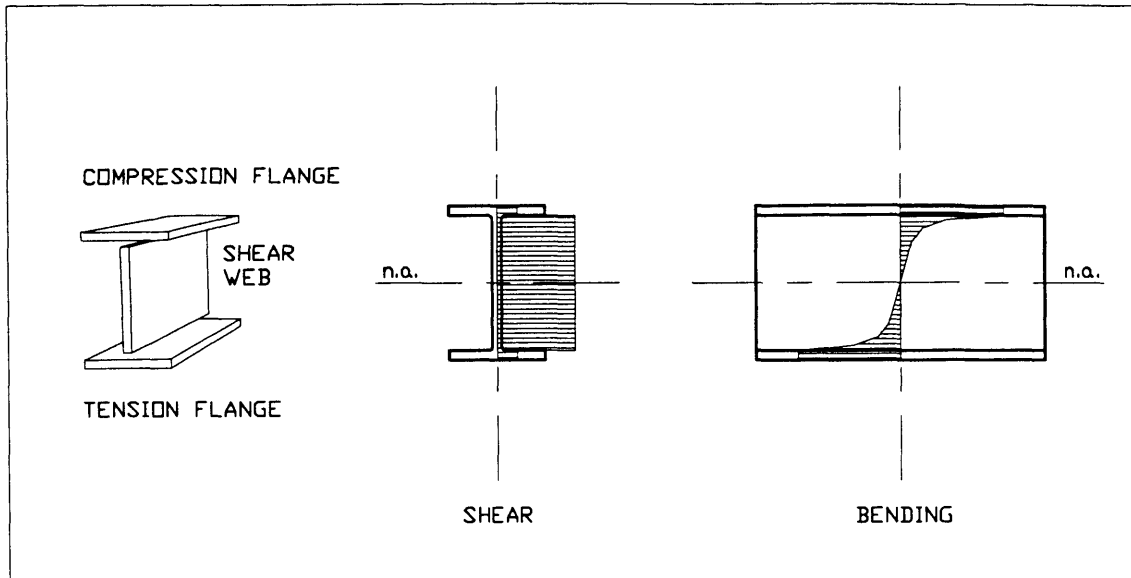


Figure 3-32: The formal makeup of a steel wideflange beam

component whose complex interleaving of element parts and connections begins to reflect the homogeneity of the original solid masonry wall! Some important questions are bound to arise out of such an exercise. At what point does the process of reduction cease to yield practical advantages in the efficiency of the elements? Even more important is the question of the efficient use of micro-optimized elements in components and schemes. Is micro-optimization consistent with the parallel industrial trend toward *macro-componentization*, the design and prefabrication of large scale, standardized building components?

The parts optimization imperative is found to permeate even the geometrical disposition of material within individual elements as is shown in the wideflange beam example of figure 3-32. Note that where once a rectangular wood beam provided the same type of structural behavior in a formally compact member, the structural steel wideflange shape, a veritable hallmark of the genius of engineering optimization in itself, has been broken down into a distinctive section, each part of which represents the nominal fulfillment of a different internal statical function. In a typical horizontal (simple) spanning application, the top flange of this beam is designed to resist compressive stresses, the bottom flange will handle tensile stresses, while the web accounts for the shear forces generated in the flanges' "coupled" interaction. The wideflange

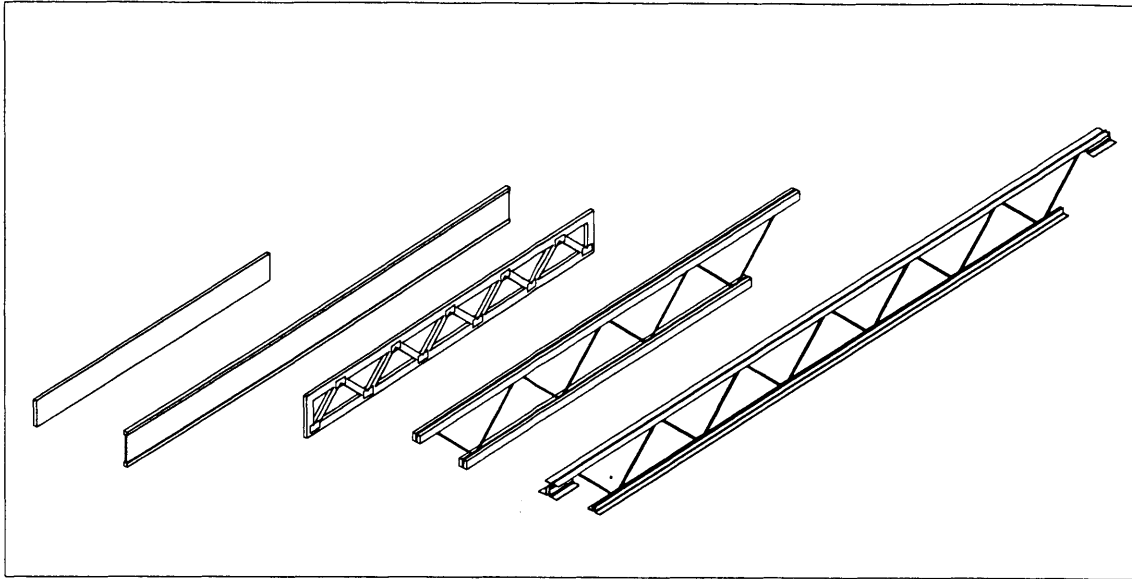


Figure 3-33: A progression from a solid wood joist (at left) to a lightweight, open-web steel joist (at right)

beam, due to its explicitly rational physiognomy, makes a more efficient use of material in bending than a rectangular section member. There now exist “built-up” wood beam shapes which imitate the characteristic section of the steel wideflange in order to optimize their spanning ability. Multiple statical functions can be shown to exist within elements of both the traditional and the industrial structural types, except that never in the traditional systems has the geometrical expression of these distinct intra-member statical functions been made so explicit as they are in the more articulated cross sections of industrially produced load-carrying members.

Figure 3-33 illustrates a transformation from the formally compact, solid wood timber joist (on the left) to the open web steel joist (on the right). Within components, these new optimized elements can become parts of a richly integrated hierarchy of interdependent structural forms.

The highly mechanized production of industrialized building elements makes easy work of the otherwise tedious cutting and fitting of many small pieces involved in making micro-optimized elements. Today this task is performed with the help of computer-controlled manufacturing. The size of components premanufactured for assembly on location is limited primarily by constraints associated with handling and

transportation. There are limits to what a truck can carry on a highway and even more so on city streets. In rail and marine transportation one is constrained by the proximity of the port or the tracks to the site. Even given the promises of large scale component fabrication for future development of the construction industry state-of-the-art (utilizing high-strength materials and composites), the question of *schematic* structural efficiency using such parts is potentially left under-addressed. In our focus on the micro-optimization of building elements, and the macro-componentization of large, two-dimensional assemblies, perhaps we neglect the most important consideration for efficient building stabilization of all. All of the advantages of optimized elements and components are lost if, in their combination, they fail to justify themselves in terms of a systematic unity on the level of an overall structural *scheme*.

3.5 Three Jointing Strategies

Inseparable from the notion that both material shape and material structural behavior contribute to the form of a part of a building structural subsystem, and the notion that we can both perceptually and conceptually “break down” the parts of a building according to their hierarchical organization, is the critical nature of the physical connections between the parts. The relationship between part and joint can be seen at all levels of assembly within a building structure, from the elements to entire schemes. Though there are as many ways to join two parts as there are parts to be joined, we can “abstract out” some basic strategies commonly used in building construction, noting their general impact on the character of the systems in which they are used.

Two very broad categories are distinguished by Alexander Zannos. One results in what Zannos calls *monolithic structure*. A monolithic structure is one “whose members are interconnected at fully fixed joints” (see figure 3-34).¹² The joints in such a structure can be referred to as *monolithic joints*. An articulated structure is one “whose members are joined with hinges” allowing relatively free differential

¹²[30, p. 105]

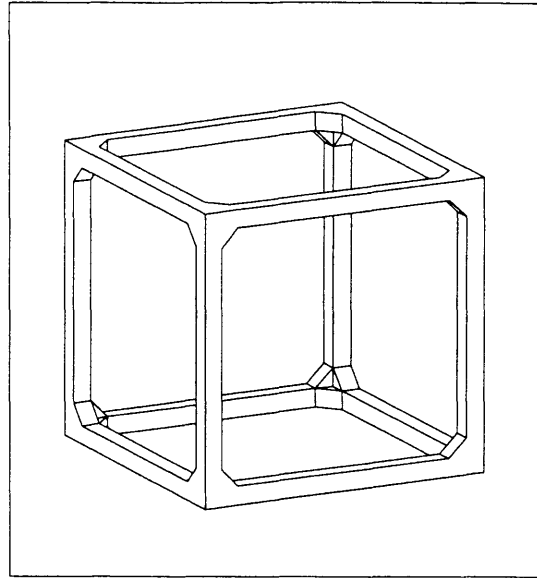


Figure 3-34: *Monolithic* structure is exemplified by its characteristically rigid member connections

movement between the members in one or more directions (see figure 3-35).¹³ These joints can be called *articulated joints*.

In addition to investigating the natures of these two types of joints, I will also propose a third category called *mediated structure* (see figure 3-36). In mediated structure, “third party” members are introduced in order to mediate the statical transfer from one member to another. These kinds of joints can be called *mediated joints*. Mediated joints involve certain aspects of both monolithic and articulated connections while adding an extra layer of complexity to the equation by nesting a new element layer into the joined assembly itself.

Monolithic Joints

In monolithic joints parts are fitted together in such a way that they become like one member. They lose something of their own individual character to, as a result, gain a new, combined form. Thus in the monolithic joint, the parts’ mutual authorship of their interconnection requires that they both reconcile themselves to the other, becoming a new entity with qualities superior to the sum of the original parts taken

¹³[30, p. 105]

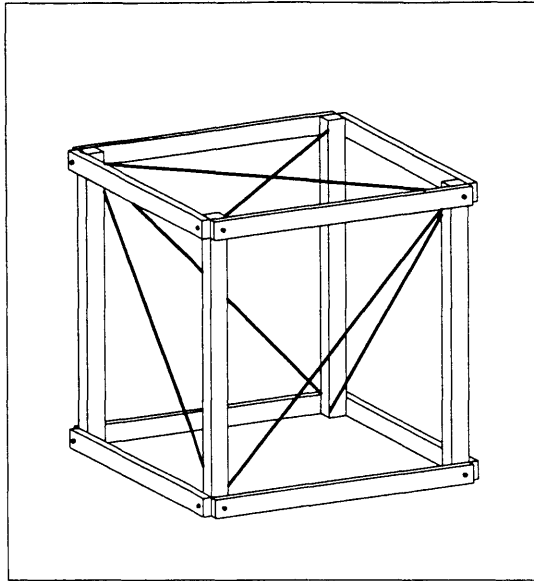


Figure 3-35: *Articulated* structure is exemplified by pinned connections between members

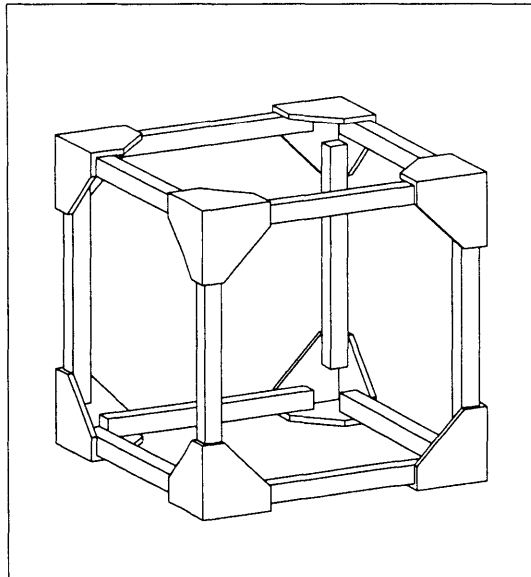


Figure 3-36: *Mediated* structure uses third party, “translational” pieces to adequately bind otherwise separated members together

in isolation. Examples of wood, metal, and masonry monolithic joints are given in figure 3-37.

This material sacrifice toward the end of a unified formal integrity is expressed both in the structural behavior of the joint and in its shape. In terms of the shape of the monolithic joint, what is most striking is the maximization of physical contact between the surfaces of the members being joined and the continuity between their geometries that tends to make the joint “go away” altogether. This smooth visual transition between members is sometimes described as a “well-fittedness” between them—a snug, tight, or densely intermeshed fit or even a total fusion of their geometries as is the case in many cast concrete joints.

In terms of their structural behavior, monolithic joints can best be characterized by the translation of many kinds of forces (axial, bending, torsional, etc.), often simultaneously, *through* the joint. Accommodation of movement or strain is taken up gradually across the whole monolithically connected assembly, primarily within the solid mass of the parts themselves— not just in the joint. In traditional, solid brick masonry construction, for example, strain is shared throughout the network of bricks and mortar joints. The concentration of movement along any one mortar joint, potentially causing it to crack, is avoided. In lighter assemblies, like wood or steel framing, this distribution of strain throughout the members themselves is achieved through strong mechanical connections between members. Bonding in traditional Japanese wood joinery is achieved through a complex geometry of surfaces, each one very carefully fitted to the next, and is often aided by pins and tenons. Monolithic metal joints rely more typically on the repetitious use of bolts or rivets or on continuous welds to achieve enough rigidity to distribute moments through them. The resulting stresses are resisted within the members internally.

The amount of rigidity necessary in a joint to give it a monolithic quality is relative to the formal characteristics of the larger structure of which it is a part. In massive stone masonry construction, for example, like that of the ancient Egyptian temples and pyramids, the friction developed between heavy stones laid one directly on the other, creating a highly crafted, smooth, mortarless compression joint, is sufficient to

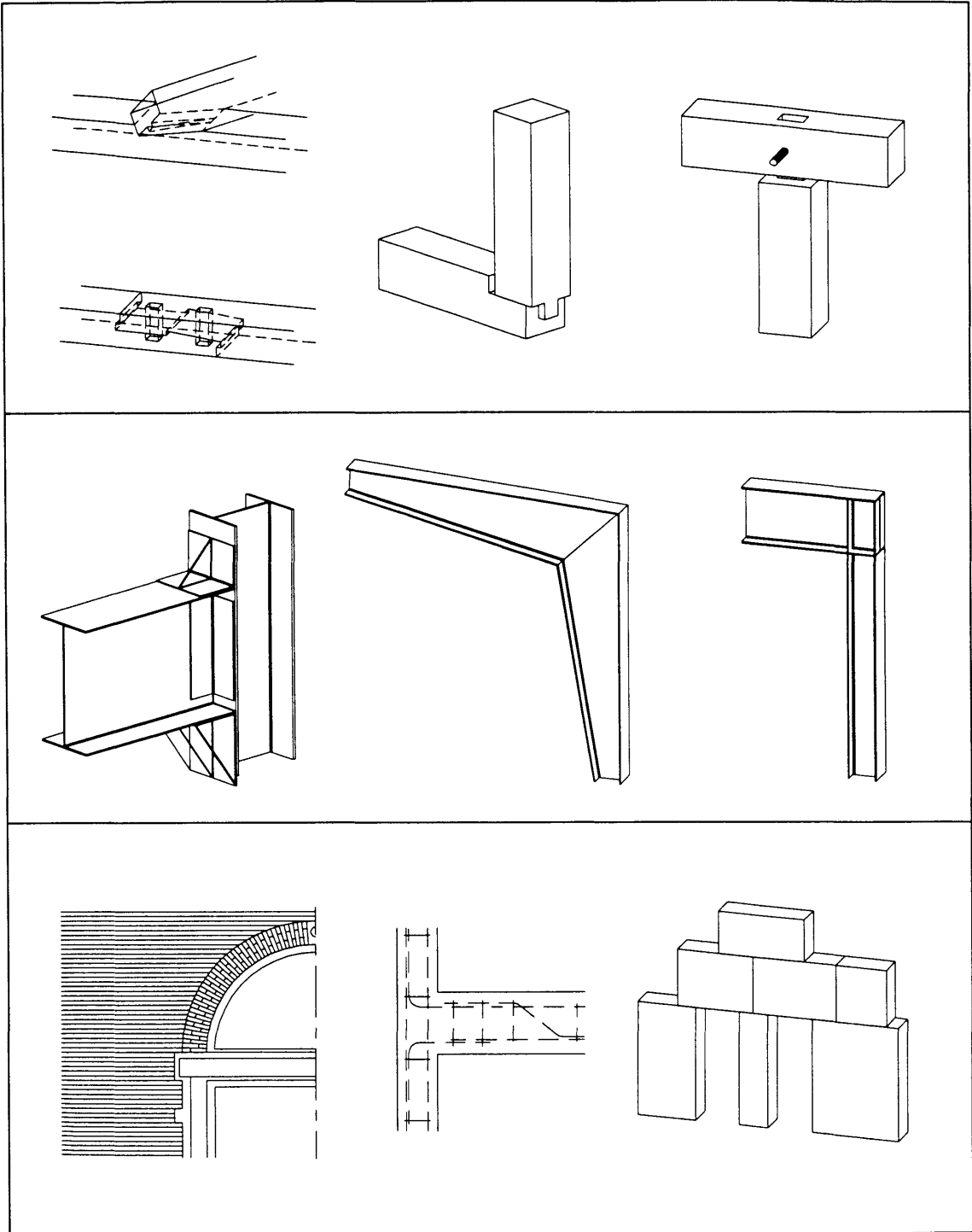


Figure 3-37: Examples of *monolithic joints*

characterize the joint as monolithic. This is clearly not a “rigid” joint in the same sense that a welded steel joint is, but, under the normal loading conditions to which it is subject, the bonding caused purely by dead loads across surfaces in full contact in much traditional stone construction is enough to unify the behavior of the total structure relative to that of its individual joints. One must also admit that the level of care and craftsmanship evident in the dry-laying of ashlar masonry, such that a full and perfect plane of surface contact is established between stones, is, like the wood joints of fine Japanese carpentry, productive of a visual as well as strictly behavioral unification of parts.

To characterize monolithic joints as “moment resisting” therefore, is to relate their individual rigidity to the statical nature of their structural scheme and not to any absolute standard established independent of the particular form of the whole structure under investigation. The classification of a joint or structural assembly as “monolithic” carries implications from the level of the individual connection throughout the hierarchy of parts assemblies in which it interacts, to the level of the larger building structural system.

Articulated Joints

In contradistinction to monolithic joint form, articulated joints embody a separation of one part from the other. As in monolithic joints, however, the character of articulated joints is evident both in terms of their spatial configurations and in terms of their statical behavior. Whereas in the case of the monolithic joint, members were fully bonded to one another, in articulated joinery one part is clearly delimited from the next, allowing movement between them differentially. These parts maintain a relatively high degree of the individual character that they enjoyed as separate objects altogether. Some examples of separated joints are shown in figure 3-38.

Articulated joints have, as integral to their form, planes of slippage which deliberately concentrate movement between the parts and block the transference of certain types of strain from one to the other, thus controlling the forces that are allowed to pass on into any given member. Points, lines, or planes of contact between bearing

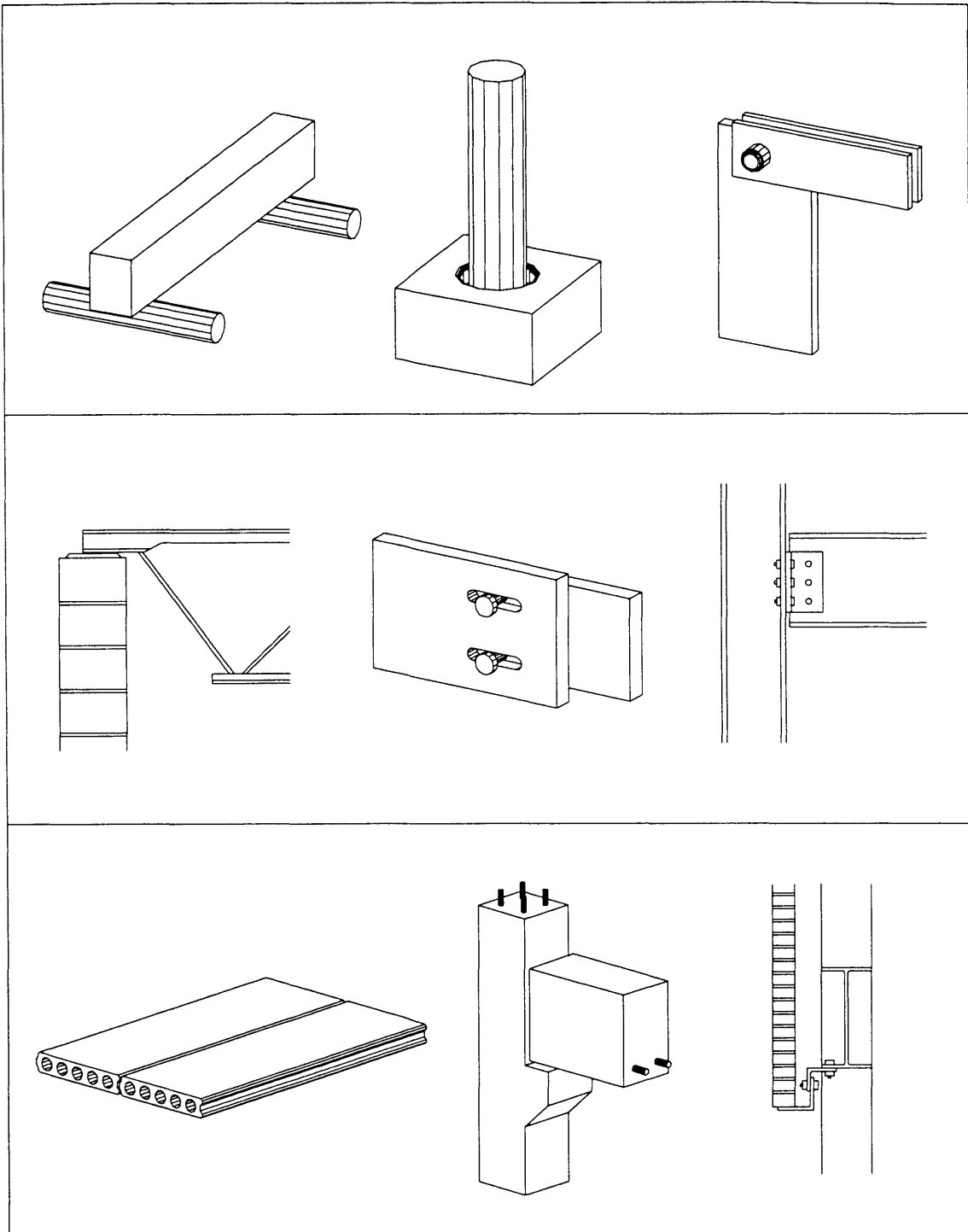


Figure 3-38: Examples of *articulated joints*

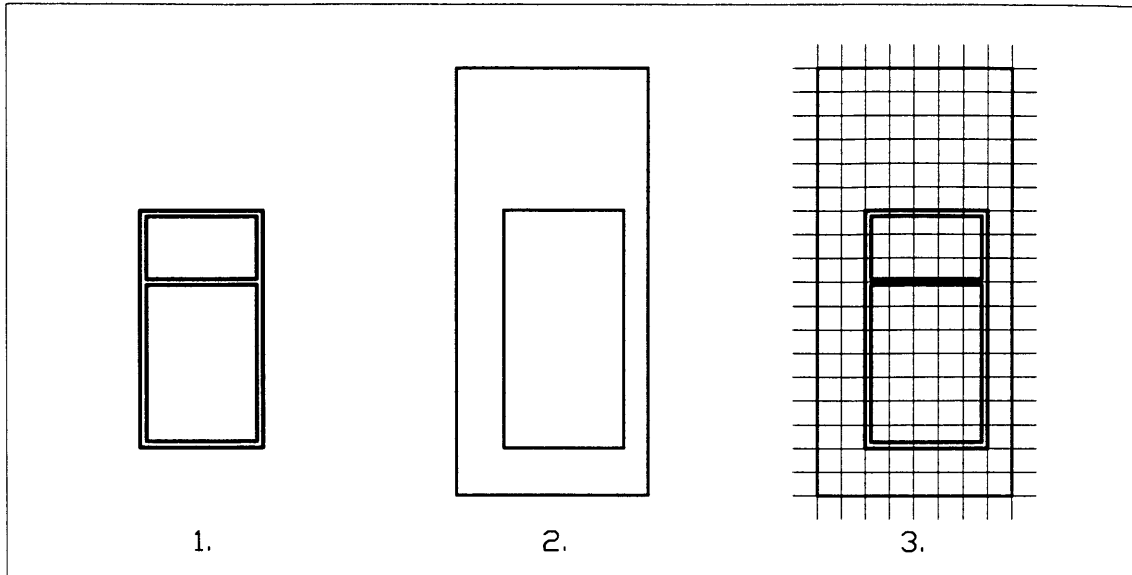


Figure 3-39: The controlling effect of the modular unit on the form of an individual part and its placement relative to the grid of a larger assembly (from Schmid and Testa's *Systems Building*)

members provide “degrees of freedom” in the statical behavior of the larger assemblies in which they are used. Hinges, rollers, lubricated plates, pins, oversized sockets, sleeves and slots are all examples of means toward articulated joinery.

Two important concepts can be associated with appropriate use of articulated joints, especially in the industrialized building construction of the past 200 years (though known to architects and builders long before). One is the concept of the *module* and the other is that of the *grid*.

Modules are steps of nominal, incremental dimensions by which parts may increase or decrease in size while still maintaining an overall dimensional coordination. A consistent modular coordination of parts conceptually guarantees their fitting one to another in many different combinations without the need to specially modify their size. Modularly coordinated parts are also, therefore, fully interchangeable (see figure 3-39). Examples of modular units of importance to building construction are the standard brick, the Japanese ken (equal to the length of one tatami mat), the 4x8 foot plywood sheet and the 16” (or 24”) stud spacing in a 2x4 house.

Repeating an array of modular units in a regular pattern yields a grid of poten-

tially infinite three-dimensional extension within which modularized objects can be placed. Grid lines are one-dimensional, abstract axes of orientation about which the positioning of any object can be conceived. These grid lines are commonly referred to as “centerlines” since one of the most useful ways of positioning an object with respect to a grid is by alignment of the exact center of the object with a grid line. The spatial, positional organization of parts with respect to these abstract “one-dimensional” lines of reference finds its most ideal and universal proponent in the equally abstract Cartesian grid. Radial, triangular, rhombic, and many other grid patterns can lend themselves to modular systems of coordination as well.

The difficulty with the idea of assembling buildings from object parts of pre-coordinated, modular dimensions within a grid of perfectly one-dimensional, imaginary centerlines is just that it *is* an idea and never quite works out in a real world of material *imperfection* where physical dimensions are not precise and, worse yet, they *change over time!* As abstract properties of the material components being arranged, the grid centerlines leave little consideration for the varying *actual* widths of the parts which, though ignorable along an uninterrupted stretch of a single line, cannot (even in theory) be overlooked at the orthogonal intersections, where collisions of the panel corners are liable to occur. This conflict of the modular parts interface is illustrated in the left image of figure 3-40 while on the right is shown the result obtained by trying to combine same size, modular component members without their colliding. The Tartan grid (middle image of figure 3-41) responds to this difficulty by expanding the notion of single grid centerlines to one of *bands* of designated area within which modularly coordinated parts can be accommodated. Parts placed within the bands of a Tartan grid can be positioned precisely, relative to the centerlines of an overarching grid, without the hindrance of their colliding with other parts at grid intersections so long as they fit within its band width.

The dimension that remains between the outer edge of the material member and the edge of the Tartan band can be thought of as a *tolerance*. A tolerance is the free space that is provided between material parts. Tolerances insure that the inexactitudes of parts manufacture, installation, and in-place operation are accounted

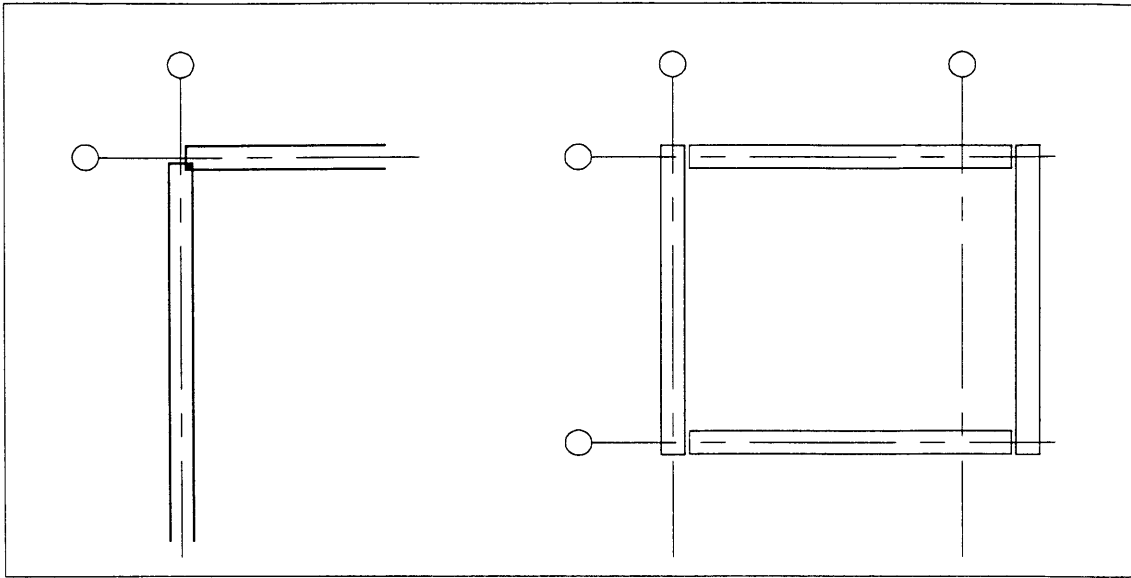


Figure 3-40: Difficulties arising out of a strict, mechanical integration of standard, modularized parts and the regular grid originate in the turning of corners and at the crossings of orthogonal grid centerlines

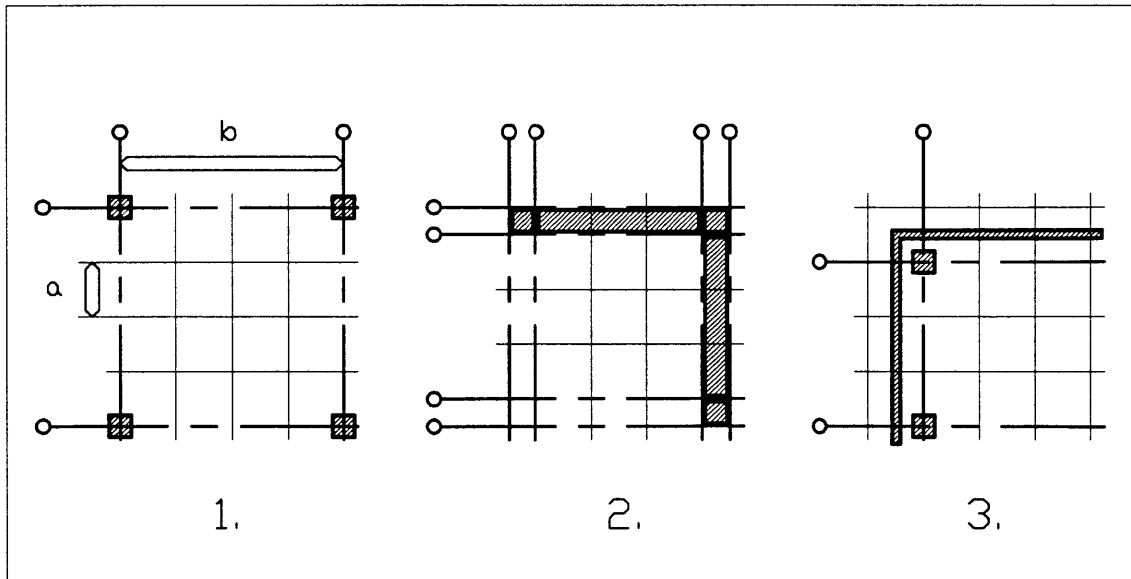


Figure 3-41: Variations in column and wall placement ranging from (1) the strict adherence of material centerlines to grid intersections, (2) material placement within the Tartan grid, and (3) a separation of structural and non-structural members affording the freedom of placement of one while the other remains fixed (from Schmid and Testa's *Systems Building*)

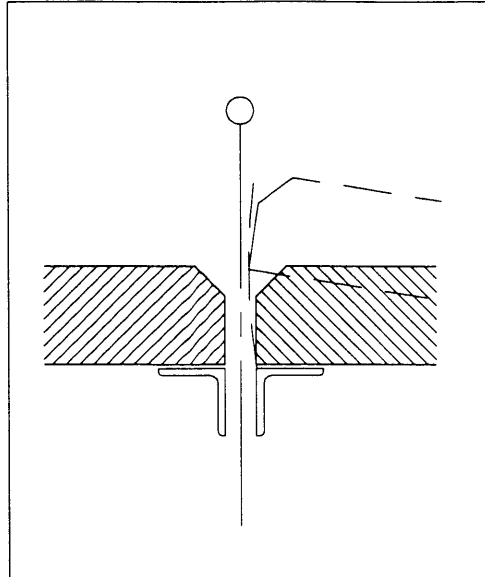


Figure 3-42: Installation tolerances insure that the parts being fitted will not conflict with those already in place (from Schmid and Testa's *Systems Building*)

for with respect to the larger structures that are made by fitting many small ones together within an overarching positional grid (see figure 3-42).

The “looseness” that is built-into such structures as a result of the accumulation of tolerances of individual parts is a fundamental characteristic of articulated structure. In fact, the notion of tolerances – tolerances to accommodate differential movement and change between parts, tolerances to accommodate individual differences in manufacture and installation – is of the essence of articulated joinery.

An interesting comparison can be drawn in the larger effects of individual jointing strategy between monolithic and articulated structure. Note that in the left hand image of figure 3-43 the importance of an “exact” joint requires that some variation in the precise dimension between joints be allowed. In the right hand image the primacy of the centerline dimensions between joints necessitates a certain degree of “slack” in the interface of members. The first example, of course, represents the general condition of monolithic joinery while the latter stands for that of articulation.

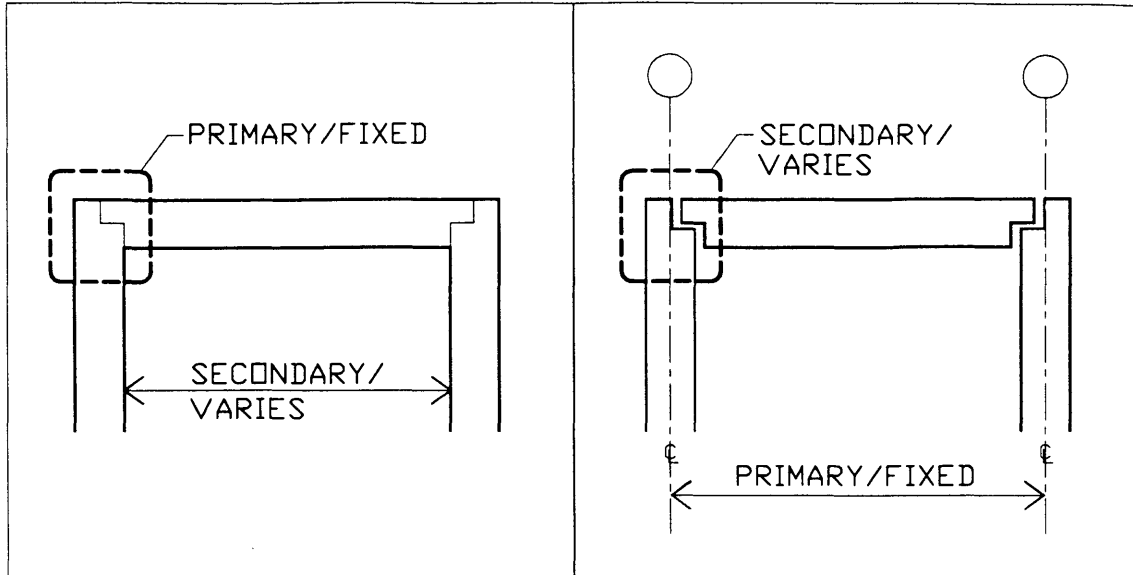


Figure 3-43: The primacy of the tight fitting joint in monolithic joinery requires that overall dimensions between connections be somewhat flexible (left image) whereas the primacy of the grid/material centerline correspondence in articulated joinery means that the special characteristics of the joint itself (especially in terms of its tolerances) must be flexible (right image).

Mediated Joints

A mediated joint can have qualities of both monolithic and articulated connections. It can be either rigid or flexible. In mediated joinery an additional material element interfaces between members thus joined, adjudicated between them while significantly influencing the formal identity of the structure as a whole. Figure 3-44 shows some examples of mediated joints.

As exemplified in multi-dimensional knuckles of space frames (see figure 3-45), mediator pieces can at once provide the requisite separation of distinct functional members of a structural component while also allowing for their positional adjustment. Further, because the connector pieces possess real material presence, they can be seen to bond directly to the members which they *indirectly* connect, adding an additional, nested layer of visual richness to the structure as a whole (see figure 3-46). In mediated joinery the restraint of one part connecting to another is objectified in the form of the mediator piece. The mediator itself thus makes a significant contribution to the pattern and texture of the component assemblies in which it is used (see

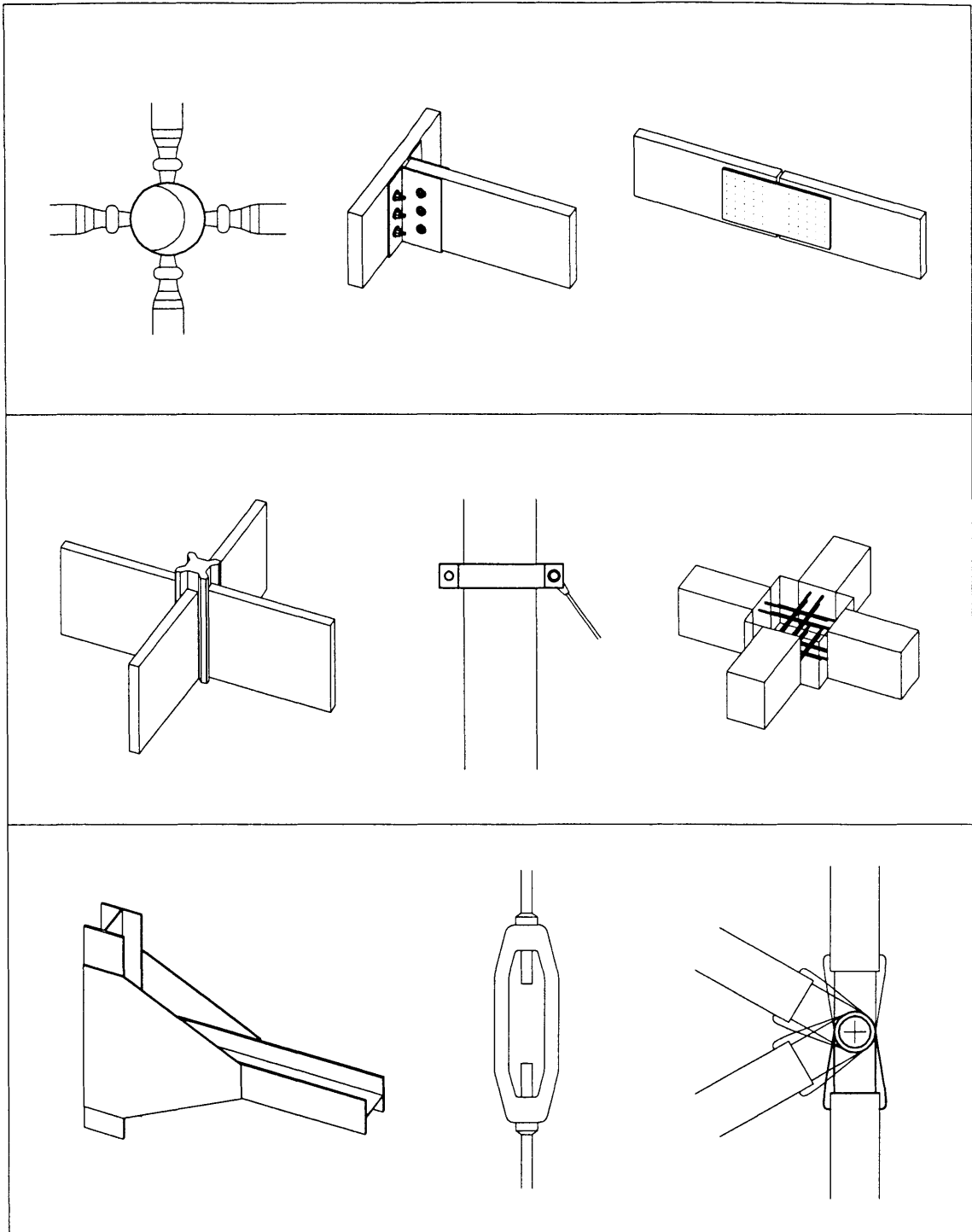


Figure 3-44: examples of *mediated* joints

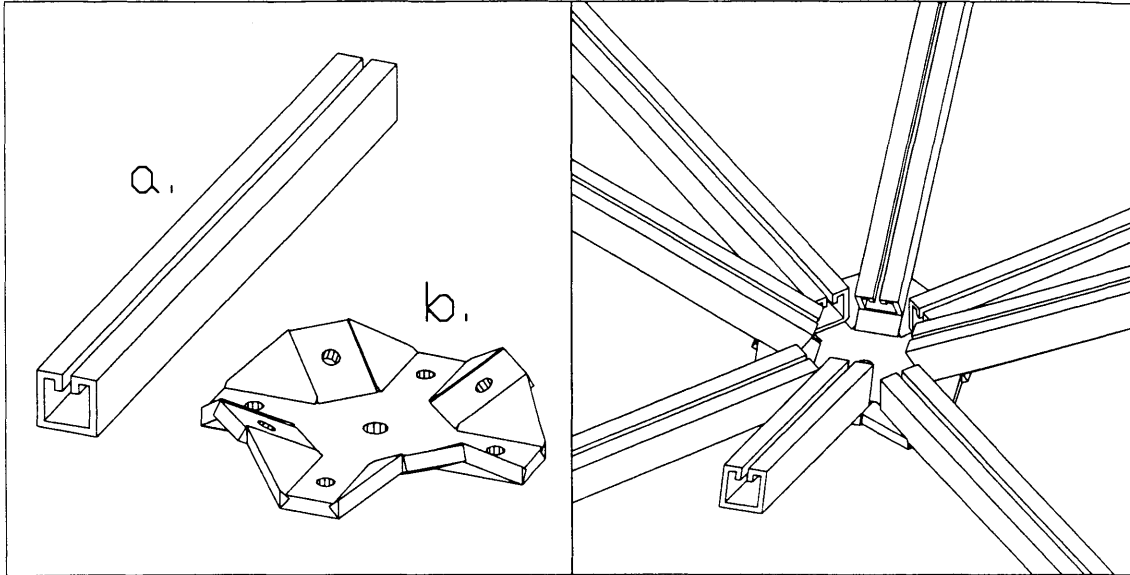


Figure 3-45: The “Unistrut” frame system developed in the 1950’s at the University of Michigan makes full use of elaborate connector pieces which “mediate” between basic chord elements

figure 3-47).

Mediator joints are characterized by their use in configurations where development of the necessary strength from one member to another is difficult to achieve by attaching them directly. This is often the case where insufficient area of contact available between members requires that they each be gripped separately, as in the joining of two cables, end-to-end. Mediator connections are also valuable when a tight fit is required between members which may vary in size or may need to be adjusted later. Here, the role of the mediator element becomes one of transference of (sometimes all of) the load between members by securing each of them directly but separately from the others. A bond can thus be developed which suits both connector and each connected part. The mediator acts as a bridge or transmitter between parts whose effective structural performance depends on how they are “indirectly” connected to the rest of the structure.

The butt joint of a timber joist to an orthogonally disposed header beam is an example of just such a condition (see the top-middle image of figure 3-44). In a direct, lag-bolted connection through the head into the beam, the head is loaded by the shaft of the bolts across its grain, in one of its strongest directions. But the

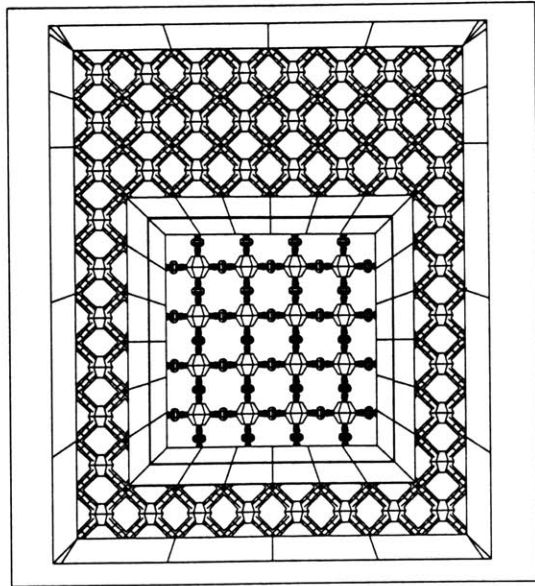


Figure 3-46: The rich patterning of spanning parts and connectors creates an effect of montage seen in the traditional Arabic screening device, the *mushrebeya*

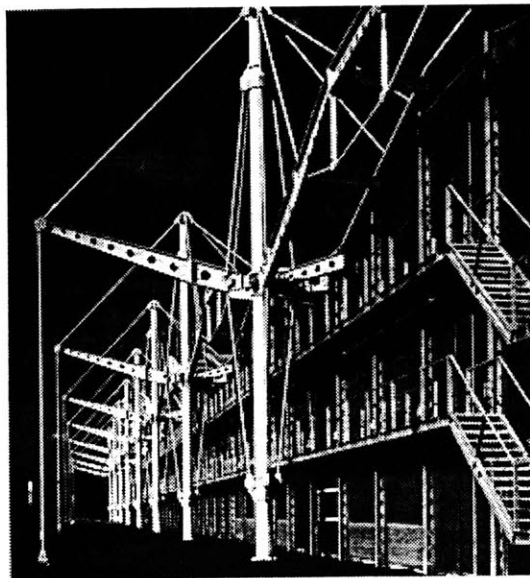


Figure 3-47: A more three-dimensional effect of montage can be seen in the prolific use of mediator joints in some of the work of British architect, Norman Foster (Renault Distribution Centre, Swindon, England, from Norman Foster's *Foster Associates: Buildings and Projects, Vol. II*)

beam is resisting the forces of the bolts running parallel with its end grain, in one of its weakest dimensions. The use of the fabricated metal hanger allows for the bolting through of both members in the same strong orientation relative the grain of the wood, getting the most structural action out of each piece while keeping the configuration of their connection simple.

Another example is seen in the use of the turnbuckle (see lower-middle image of figure 3-44) to both procure a strong joint between parts which are inherently difficult to connect to each other directly and, at the same time, to provide for the fine adjustment of the tension force between them. The ability to adjust the statical characteristics within a single mediated joint has implications for the formal characteristics of the larger structure of which it is a part. Here is a good example of a change in one part of a system producing changes in all of the others.

Mediator joint can be raised to a “universal” status by applying a single connector piece to multiple connection configurations. Conrad Wachsmann’s adjustable, universal joint is an example of such a versatile element. In concept, it concentrates the solutions to many connection problems in a single, small, repetitive, but highly adaptable fabricated metal “hinge” (see the lower-right image of figure 3-44).

To connect parts by means of monolithic and articulated joints, some compromise has to be made in terms of a tolerance either in the dimensions between joints or in the “play” of the connections themselves (recall figure 3-43). Unique to the form of the mediated structure is the ability to internalize this tolerance within the third-party connector elements themselves. As depicted in figure 3-48, mediated joints allow for a high degree of accuracy both in the positioning of the members (relative to an overarching column centerline grid, for instance) and the exact (and potentially rigid) configuration of the joints themselves.

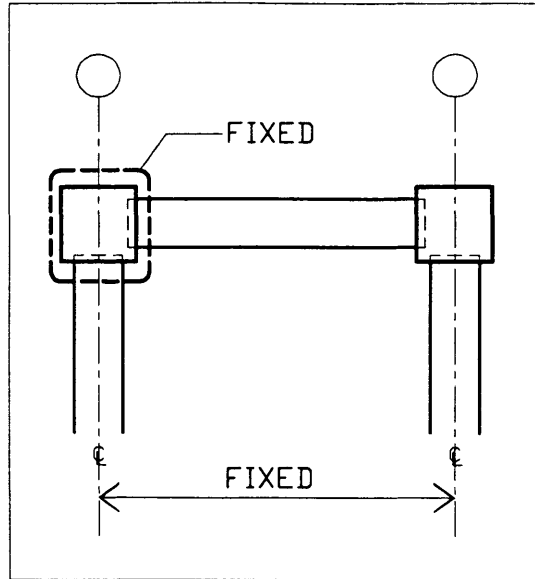


Figure 3-48: Mediated structure allows for both the precise placement of connected members *and* their “tight” spatial and structural configuration

Chapter 4

Hypertext Specifications Format

4.1 The Specifications Document

The two primary media in professional architectural representation are the graphical media (drawings) and the textual media (construction specifications). Drawings and specifications combined comprise what are known as the *contract documents* – the description of a building *in potentia* which is the basis for a legally binding construction contract between an owner and a builder. Although both the drawings and the specifications contain information about the same building-to-be, the specific types of information they convey as well as the form of the media through which they convey it are quite different.

A representation may reproduce one aspect of the form of its subject faithfully while (purposefully or otherwise) being negligent in terms of another. A plan drawing, for example, is usually highly descriptive of the relative lateral positioning of the walls of a building with respect to its larger site. At the same time the plan intrinsically gives little information as the vertical positioning of the building's components. Vertical information is made clear in the elevation and section drawings. In general, different types of drawings provide different kinds of information about the building's geometry and disposition. Because the relationship between the information in one drawing is coordinated with that given in others (often with the help of notes and keys and symbols), they all work together to provide a unified graphical documentation of

the spatial aspects of the entire building.

If the purpose of the drawings is to establish “the design, location, and dimensions of the Work,”¹ the role of the specifications is to document “requirements for materials, equipment, construction systems, standards for workmanship for the Work, and performance of related services.”² The drawings can be said to be isomorphic to the actual building in the familiar sense that they consist of pictorial likenesses—scaled spatial representations of the building cut in plan and section and seen in elevation. That the organization of graphic images in a set of architectural drawings supports a sense of the systematic relationship between various parts of the building is evidenced in their hierarchical presentation on paper, traditionally ranging in order from the largest scale overview of the project down to its most minute detail. There is also often a “vertical” order to the contents of the graphic documents beginning with the ground or entry level and proceeding upward to the level of the roof.

The relationship between the specifications and the building is not nearly as transparent. Specifications are the “written, verbal description of work to be performed,”³ the legal and technical description of the transformation of basic material elements into finished assemblies and finally a whole building. Specifications are conventionally grouped into subcategories of the work of construction known as *divisions* and *sections*. These are the basic chapters of a specification. In the dominant specifications format used in the United States (and the one used for comparison in this paper), the Construction Specifications Institute’s Masterformat, the divisions and sections have been given five digit numerical codes to facilitate their filing, inventory and sequencing within the document. The thousands and ten-thousands digits indicate the *division* of the contract for construction to which a particular section belongs. There are 16 divisions in Masterformat. They are listed in appendix A. Individual section numbers (individuated by the contents of the hundreds, tens, and ones digits) indicate a further subdivision by subject matter. Section number 03200, for example, pertains to reinforced concrete, falling under division 03, concrete. Sec-

¹[3, 1.1.5]

²[3, 1.1.6]

³[21]

tions are the more precise classifiers of tasks and materials required for the job while divisions organize the major headings of the work of the contract (see appendix A for a listing of the division and section headings used in CSI's Masterformat). The five digit CSI numerical listing of specifications sections can be simplified, using what are known as *broadscope* specifications, or expanded with *narrowscope* specifications. Broadscope specifications typically use only the ten-thousands, thousands, and hundreds digits to indicate section number while the use of all five of the digits to make finer differentiation between specifications sections of more specific content is typical of narrowscope. Broadscope and narrowscope specifying serve the purpose of establishing either broad or narrow "frames of reference" for the grouping of information as the needs of the project may dictate. Broadscope sections cover their material in more general and overarching ways while narrowscope sections go into more detail. The more complicated the job, the more narrowscope sections are likely to be used.⁴

Within the individual sections, information is grouped under one of three parts. Rosen describes them thus:

Part 1, GENERAL, is concerned with the ground rules under which work is to be performed, and it also establishes the scope of the work to be performed within the section.

Part 2, PRODUCTS, is intended for descriptions of materials, equipment, fixtures, and for the manufacturer's process used in the development and production of products. The latter requirement includes mixing and fabrication which are inherent in the manufacturer's process, whether performed on or off the site.

Part 3, EXECUTION, is used to describe in detail the workmanship, erection, installation, and application procedures.⁵

Within each of these parts there is a further division of statements into *articles*. Articles are given major headings like those shown in figure 4-1.

⁴Note that the list given in appendix A includes both broad and narrowscope section headings.

⁵[21, pp. 23-24]

Part 1 GENERAL

SUMMARY

REFERENCES

DEFINITIONS

SUBMITTALS

QUALITY ASSURANCE

DELIVERY, STORAGE, & HANDLING

PROJECT/SITE CONDITIONS

Part 2 PRODUCTS

MANUFACTURERS

MATERIALS/EQUIPMENT

MIXES

FABRICATION

Part 3 EXECUTION

EXAMINATION

PREPARATION

ERECTION/INSTALLATION/APPLICATION

FIELD QUALITY CONTROL

ADJUSTING/CLEANING

* * *

Figure 4-1: Outline of the major article headings within a conventional specification section

1.1 Article

A. Paragraph Heading

1. subparagraph

a. subsubparagraph

1) subsubsubparagraph

Figure 4-2: Outline of the paragraph format in conventional construction specifications (from Harold Rosen's *Construction Specifications Writing*)

In general, the format for the organization of information within each article is given in figure 4-2.⁶ An example specifications section whose organization follows the conventional format described above is provided in appendix B.

Although hierarchical in its respective arrangement of headings, paragraphs, subparagraphs, etc, of figure 4-2, this conventional formatting of the specifications text is primarily *linear* in organization. That is, like this thesis paper, it has a beginning, a middle and an end and is intended to be read in order. The sections and divisions have historically been organized according to the division of labor between the various trades that contribute to the construction of the building, also in a roughly linear, chronological order (according to the order of tasks to be performed in a conventional construction sequence—see list of sections in appendix A).⁷ This is an administrative abstraction, established for the convenience of the general contractor or construction manager's estimating and bidding of the job, and is not an abstraction of the layout of the building in the same sense that the drawings are (focusing on the spatial, geometrical characteristics of the building) nor is it a documentation of the formal contributions of the parts of a building themselves, toward the condition of an overall system at project completion.⁸

⁶[21, p. 27]

⁷[21, p. 13]

⁸Interestingly, in support of my criticism of the conventional, "division of labor" emphasis of specifications, AIA document A201, the *General Conditions of the Contract for Construction*, states that

Since the trades involved in a construction project can be generally associated with the materials with which they work (carpenters with wood, masons with masonry, roofers with water-shedding materials, etc), building parts covered in the conventional specifications format tend to be grouped according to their material type instead of according to their physical, internal interrelationships as interconnected parts within a building's system incorporating many types of materials and the expert work of many trades working together toward a common objective.

A further tendency in the current organization of the specifications text is to specify precise methods and procedures by which the trades are to carry out their respective portions of the work. This produces what are known as "prescriptive or "process" specifications. A typical example of this kind of language (in this case dealing with the planting of trees described in section 02900–Landscaping) reads:

1. Fill holes with backfill mixture consisting of three parts soil taken from the hole and one part specified new soil.
2. Fill to proper height to receive plant and thoroughly tamp the mixture before setting the plant.
3. Set the plant in upright position in the center of the hole and compact the backfill mixture around the ball or roots.
4. Thoroughly water each plant when the hole is two-thirds full.
5. After watering, tamp the soil in place until the surface of the backfill is level with the surrounding area and the crown of the plant is at the finished grade of the surrounding area.⁹

Prescriptive specifications tell the contractor what to do, how and when to do it. This scope of interest in the construction process itself can be troublesome for the

Organization of the Specifications into divisions, sections and articles and arrangement of Drawings shall not control the Contractor in dividing the Work among Subcontractors or in establishing the extent of Work to be performed by any trade.

[3, 1.2.4]
⁹[16, p. 418]

architect who is not advised to take on legal responsibilities which more properly lie with the contractor.¹⁰ All specifications using the CSI Masterformat numbering system are at least partly prescriptive. If not in the actual wording of the documents using Masterformat, prescriptive insinuation is inherent in the numerical order of its sections which suggest an intended sequence of construction, from pre-construction, to site work, to foundations, to superstructure, to interior finishes, etc.

At the opposite extreme from prescriptive wording of a specification is the *performance* specification. A performance wording of the specification indicates the end result that is desired by the architect and owner, usually in terms of the behavior or performance of the product or assembly in question. The means of achieving the criteria set down in a performance specification and the methods of fabrication and construction used on the project are left up to the individual manufacturer or contractor. A passage from a typical performance specification reads,

Provide guardrails capable of withstanding:

1. a point source horizontal load of 500 lbs. and,
2. an evenly distributed horizontal load along its length of 50 lbs. per foot.

A performance specification can address any aspect of the form of a product as long as the criteria given are capable of objective measurement. Often the test methods used for verification of conformance are also stated explicitly in the text.

A major difficulty in the use of performance specifications is the prospect that no product readily available on the construction supply market will satisfy the criteria of

¹⁰AIA document A201, the *General Conditions of the Contract for Construction*, in one of the pillars of that document, states that

The Contractor shall supervise and direct the Work, using the Contractor's best skill and attention. The Contractor shall be solely responsible for and have control over construction means, methods, techniques, sequences and procedures and for coordinating all portions of the Work under the Contract, unless the Contract Documents give other specific instructions concerning these matters. [3, 3.3.1]

By explicit specification of such "means, methods..." within the contract documents, the owner often assumes unnecessary liability.

a given specification. This may necessitate a relaxing of the standards of the specification once the project has gone out to bid so that reasonably priced products may be used in the building, or a special item may have to be custom fabricated. The latter can be an expensive alternative. Another problem with performance specifications is that products which are relatively new to the construction market will lack the benefits of the “test-of-time.” It is difficult to guarantee the in-place performance of a product over years of use when the product has not been around long enough to validate the claim empirically.

Certain governmental and public institutions require performance specifications on the grounds that they encourage free competition among many vendors for any given part of a building. But performance specifications tend to be long and wordy because they have to describe every aspect of a product’s character that is in any way important to the building as a whole. In cases where an off-the-shelf product is likely to be used anyway, such verbiage becomes a reiteration of much of the manufacturer’s own product specifications. This is why pure performance specifications are not typically used on commercial or residential construction projects, where brevity is a virtue. A much more economical alternative for these types of projects is to use a *proprietary* specification.

Proprietary wording of the specifications, often associated with *closed* specifications (those that are not open to free competition between prospective building materials and services suppliers) uses proper names of manufacturers and products (as called out in under the Manufacturers article heading of the conventional specification format), such as in the example:

Aluminum wall panels shall be Alcoa #20XB40-A “Alumiglaze.”

A proprietary specification makes clear that certain particular products are to be used in certain parts of the building. That they are to be correctly installed according to the recommendations and instructions of their manufacturer is implied.

A common criticism of proprietary specifications is that they inhibit free competition amongst vendors by inviting only a select few to bid their products for a job. The current trend in the construction industry toward the *assembly* of buildings from

many commercially available, industrially mass-produced building *elements*, however, encourages the architect to simply chose which ones are acceptable for a particular application and, instead of describing the internal make-up of each one in detail, just *name* them for inclusion in the project. This procedure saves much time in the making of a specification, while with the rise of the number of commercially available building elements, it is usually possible to specify a list of approved products as candidates for a part of a building and let competitive bidding take place between them. Other manufacturers who wish to add their own products to the list can apply for the approval of the architect or can be bid by a contractor or supplier as an “alternate,” proposed for the consideration of the project owner and architect after all of the bids have been received.

Both proprietary and performance specifications, if written properly, avoid prescriptive language and, at least in this sense, put their emphasis on the final form of the building they describe. They are, however, extremes in the sense that they represent respectively the “all” or “nothing” of specifications writing. Performance specifications describe *everything* about a product while proprietary specifications explicitly describe almost *nothing*. In most cases a combination of the two is appropriate.

What is known broadly as “descriptive” specifications convey the required physical characteristics and attributes of the product in question without necessarily establishing its performance criteria (even though they may be conveyed implicitly) and without actually mentioning any specific trade names as proprietary product selections. The example conventional specification section given in appendix B is a descriptive specification. This is perhaps the most flexible method of specifying and is most commonly used in the construction industry today.

4.1.1 Alternate Specifications System Objectives

The drawings elucidate locational information. They describe the disposition of building parts with respect to a common spatial context. In so doing they provide a kind of abstract simulation of the mutual visual interaction of the objects of direct perceptual

experience (in this case, the building) and an observer. The specifications perform a different role. It is their job to document the intended contributions of the system, its subsystems and parts through description of the specific characteristics through which the overall behavior of the building can be predicted. The specifications, therefore, drive at the essential qualities of the parts that make possible a full systematic functioning of the whole.

In any isomorphic representational relationship, the clarity of the abstract representation is dependent on the clarity of the frame of reference within which the referent is made unique (or individuated). A major distinction between the isomorphism of the typical architectural graphic image and the building to which it refers and that of the specifications text and its building is that the overarching frame of reference of the drawings is the spatio-geometrical world of the building site and the parts disposed in certain ways within it (ways in which we are enthusiastically interested as architects), while that of the specifications is the idea of the building *vis-à-vis* how it functions properly. Remember, however, that the main context within which conventional (CSI) specifications are conceived is the managerial and temporal world of the general contractor or construction manager's administration of the project and not the physical building object itself. Although the conventional methodology does address issues of the building's logical form (by rationalizing the sequence of events leading to its completion) and many of the specifications sections internally are descriptive of the intended results of building parts as physical objects, the focus of the overall format for its presentation of specifications information is not the form of the building *per se* but rather issues indirectly related to it, i.e., issues of process and not product.

The logical, hierarchical structures which organize the behavior of building systems we interpret from our direct visual perceptual experiences of architecture in its real, spatio-temporal context can be applied to an "object-based" organizational structure of the building in words and phrases as well as in the familiar context of pictures. Though as removed from the original experience as speech is from sight or touch, the format for an object's communication in written media can maintain some

important aspects of its form.

It is my contention that inspiration for just such a strengthening of the isomorphic bond between specifications text and building object can be found in terms of the interrelationships of the forms of parts to the building whole, introduced in chapter 3 as the essence of the systems phenomenon in architecture.

The specifications document format should itself reinforce the hierarchical systems order of actual buildings while placing each part and assembly within its proper context *vis-à-vis* the intended organic behavior of the building whole after construction is complete. If this is to be accomplished, relationships of one particular part to others around it, traditionally shown most clearly in terms of their positional dispositions primarily through graphic media (the drawings), must now also be as concisely addressed in terms of all of their systematic interrelationships through textual media.

Further, a specifications format should facilitate both the authoring and the reading of its documents and, in so doing, bring the written medium of the specifications into the design process as a partner to the drawings in the development of the building.

4.2 The Proposed System

4.2.1 Computer and Hypercard

The use of computers for the storage of text and the organization of its entry and retrieval has had a major impact on the development of specifications writing.¹¹ First, word processing revolutionized the way specifications are assembled. Subsequently, more sophisticated means of electronic data management have been developed. Many of the issues which come to the fore in the shift from paper-based to electronic media are not new ones but rather traditional ones re-visited. These issues can be categorized with respect to their impact on either the authoring or the access (reading) side of any system's use.

¹¹Architectural Record, June 1989, pp. 159-165.

In accessing information from a database (reading the information it contains) one is primarily concerned with the cogency of the text relative to its subject and the ready reference to related material it makes, implicitly or explicitly. In short, one wants to be able to find the information that one seeks but also to be informed and reminded of facts which support and expand it whether these leads are pursued or not. The reader is also interested in maintaining a kind of overview or summary idea of the total package of information being presented while easily exploring more detailed sections of text if further information is required.

It is of primary importance that no ambiguity is encountered within the text – i.e., that its meaning is found to be clear. To achieve clarity of the meaning of the work overall, the reader must have some basic understanding of the organization of its various sections within the whole document. In this respect, the reader desires that the organization of the document be somehow transparent over and above its content –i.e., that its format suggest an organizational framework within which one can direct one’s reading while still maintaining a sense of an “overall” context.

The interests of the building specifications writer lie in the efficient conveyance of information to the reader (this is the intention of any writer). The specifications document, however, carries the additional status and responsibility of comprising the terms of a contractual agreement between two parties. Unlike most other forms of writing, it is a legal document by which the builder’s and owner’s investments are safeguarded. It is also a set of instructions to the builder that answers the question, “what is the finished product to be?” The specification must be at once complete in its coverage of all aspects of the building’s form while also concise in its presentation of a potentially vast body of descriptive information at varying levels of detail. The author seeks, therefore, to omit nothing from the document which might leave the building’s form open to chance or to the whim of the builder. At the same time the author intends to minimize redundancy and to economize the language of the text. Systematization of the organization of the document through an ordered formatting of its text is both a traditional and a “high-technology” solution to this balancing of completeness and economy in the authoring of building construction specifications.

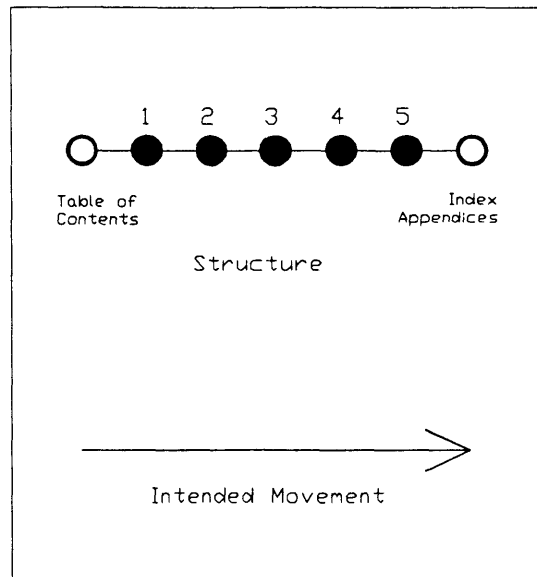


Figure 4-3: A linear structuring of information common to paper-based text media

Despite their differences, one issue that seems more than any other to interest both the reader and the writer of construction specifications is the sense of order and the clarity of the overall structure of the document. This is the issue of how smaller, individual segments of information are bound to others like them and to broader categories of which they are subsets, finally converging at the level of the whole work as one unified body. In other words, both the reader and the writer have concern that the *parts* of the document, though differentiated, individual entities in and of themselves, be presented in such a way that their contribution toward a larger, continuous *whole* is apparent.

In the traditional, paper-based, specifications document the joining of parts of text one to another is accomplished by establishing unique labels for them so that parts can be cross referenced and categorized. Since the printed pages of the specifications book are arranged in a linear, sequential manner, locating referenced parts is facilitated by the use of tables-of-contents and indexes, additional pages which act as maps of the order of the rest of the document (see figure 4-3). Since electronic media need not share the constraints of linear organization that the sequential pages of a book impose, the computer suggests a liberation from the constraints of sequential storage and presentation, but also a confrontation with the task (the responsibility)

of imposing a new structure on the informational content of the document. Electronic media beckons a new format for the economical authoring and access of information relevant both to the possibilities inherent in computer technology and to the objectives of the specifications document.

The term *hypertext* was coined by Ted Nelson in the mid 1960's to stand for the concept "of linking the world's information threads for desktop video terminal retrieval."¹² Vannevar Bush, who was an early proponent of what Nelson later called hypertext, sought

to liberate us from the confinements of inadequate systems of classification and to permit us to follow natural proclivities for "selection by association rather than indexing."¹³

Bush further criticized conventional "paper file" as the basic module of information storage and the "book-type" document organization, explaining that:

our ineptitude in getting at the record is largely caused by the artificiality of systems of indexing. When data of any sort are placed in storage, they are filed alphabetically or numerically, and information is found (when it is) by tracing it down from subclass to subclass. It can be in only one place, unless duplicates are used; one has to have rules as to which path will locate it, and the rules are cumbersome. Having found one item, moreover, one has to emerge from the system and re-enter on a new path.¹⁴

In devising new systems of information management, unencumbered by the inadequacies of traditional paper-based indexing, consideration had to be given to the

¹²[11, p. 5] Hypertext is often regarded as part of a larger category of multimedia (including text, graphics, video, audio, etc.) information linking called *hypermedia*. My use of the term hypertext does not preclude the combination of graphic and textual media but merely indicates an emphasis for the purposes of this study on the handling of the textual component of construction contract documents.

¹³[14, p. 15]

¹⁴[14, p. 14] Bush developed a mechanical device for more efficient manipulation of information called the *memex*. The idea came to him first in the mid 1930's. It consisted of "a desk with translucent screens and motors for rapid searching of microform records." [14, p. 15]

level of understanding of the structure of the overall system (which may in fact be quite complicated mechanically or electronically) that could be expected from users whose everyday experiences of environmental media revolve around the logic of sense stimulation received from common tactile objects and not electrons representing “information” moving through semiconductors. This is where the programming and management of the “structure” of a database becomes important. A primary challenge in the development of new systems of information formatting is to make their overall structure (as presented on a display screen, for example) somehow intuitively apparent to their users while still taking advantage of the facilities of information movement, storage, and distribution which are the strong points of electronic information technology and hypermedia.

Out of this dual imperative has come terminology to help bridge the gap between the sensibly apparent and the micro-electronic. An example is the word *node*, the microfeature of a hypermedia system, often also known as the *chunk*.¹⁵ Nodes represent the basic building blocks of a database. Whether consisting of a word, number, phrase, paragraph, or chapter, they are the informational “substance” of the system. *Links* are the connectivities between nodes. They represent the interrelationships between chunks of information. They are the manifestation of relationships between parts of information in the same way that load transfer through material connections in construction can be thought of as the manifestation of the relationships that exist between the physical parts of a building structure. Arranged in larger networks, nodes and links can form “a variety of possible structures such as webs and hierarchies.”¹⁶ The term *navigation* is often used in this context to refer to the sense of “orientation” and “movement” through a network of links and nodes experienced by the users of a hypermedia system.

Macintosh has made the ready manipulation and structuring of information in the form of electronic databases accessible to computer users of average proficiency and with little or no background in computer programming. Claris Hypercard software

¹⁵[29, p. 4]

¹⁶[29, p. 4]

is exemplary in this respect.¹⁷ Its removal of the traditional barriers to computer programming has made it an excellent tool both for the investigation of this alternative specifications formatting system as well as for the architectural and building construction professions in general.

Hypercard has been defined as

a program that helps you write your own programs,...a set of tools, like a pencil, ruler and piece of paper you use to create a blank paper form that will be reproduced in quantity. The form then becomes a tool to make information gathering and display easier for you and others.¹⁸

Its operation is predicated on the notion of “information threads and links,” which I have likened above to the building organism as a combination of *parts* (or nodes) and *interconnections* (links), producing a *systems* phenomenon not unlike that described in chapters 2 and 3.

The structuring of information in Hypercard can be viewed as analogous to a spider’s web which is formed by a network of interconnected threads wherein any single point of intersection can be arrived at via multiple paths. Each intersection can be thought of both as an element distinct in itself and as a small piece of a larger (potentially infinite) tapestry of similarly integrated elements (see figure 4-4). Hypercard can also be viewed as a tool for the construction of hierarchically ordered subsets of information wherein a distinct classificational order may be established and maintained to an equally complex and far reaching extent as that of the web structure (see figure 4-5). Both of these forms of organization stand in contrast to the linear form of the traditional, paper-based document (see figure 4-3). As with the parts of a building structure, no single fact (or chunk of information) exists in a vacuum, devoid of intimate contact with parts residing on more detailed scales nested within it, and with larger, more general assemblies (or categories of information) of which it is a part. The mission of Hypercard is to facilitate the ordering of such related parts so

¹⁷Hypercard is a registered trademark of Claris.

¹⁸[11, p. xxxiii]

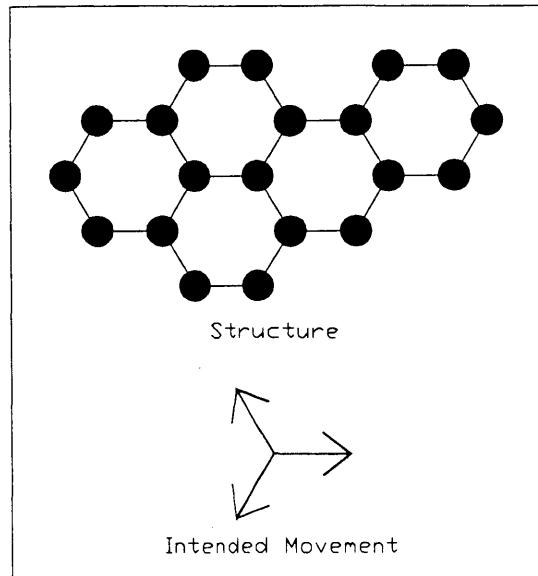


Figure 4-4: A structure of information organized as a web of interconnected nodes and links

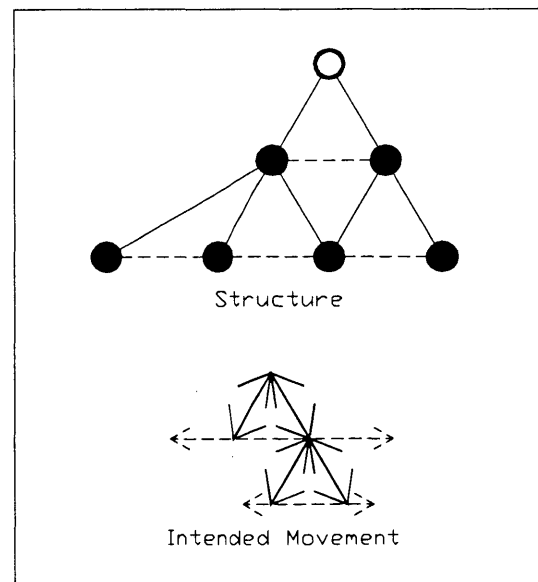


Figure 4-5: An hierarchical organization of information links and nodes

that the material being presented or assembled is coherent within whatever context is established (albeit temporarily) as the level of focus.

This context can also be seen as a “frame of reference” or “scope” which can vary according to the level of the user’s intended inquiry into the a system’s database and the type of information that is being sought or deposited. In the world of textual media, a traditional example of multiple frames of reference is seen in the fundamental, hierarchical relationship between a sentence, a chapter, a book, and an entire library. The difference with electronic text media like Hypercard lies in the ability of the author and the user to extend multiple links between individual pieces of information files as is done in a relational database. Hypercard also has the ability to manage files through its recognition of their labels or tags which can be used to sort, mark, and retrieve specific chunks of information filtered out of a much larger and potentially unwieldy mass of data.

Although Hypercard is not a true relational database, it can perform certain operations found in relational databases. Links between information within the system are easily established and modified, allowing the user to quickly navigate to a precise bit of detailed information or to pull backward within a hierarchical tree structure of files to view their larger context.¹⁹ It can also search and sort information, temporarily re-ordering files for a sequential display to meet the needs of the user. Unlike true relational database managers, which are usually designed to manipulate figures and print reports, Hypercard is intended primarily for searching and browsing through a collection of information and for the facilitation of orderly information gathering and storage.

Hypercard’s fundamental division of information files is into groups of nodes called *stacks*. A stack usually contains a homogeneous collection of information – i.e., its contents are related to each other through a sameness of kind. It can be likened to a drawer in a card catalog within which one might expect to find stored information

¹⁹Navigational links between pieces of information within a single, unified body of text, such as a book, are called *intratextual links* while those that relate parts of distinct but associated larger works are known as *intertextual links* [14, p. 36]. Both of these terms are consistent with the non-linear nature of the hypertext medium.

relevant to a common subject or sharing some filing criterion such as alphabetical or numerical order.

The format or layout of the information within a particular stack (or stacks) may be consistent as well. In Hypercard, this consistency can be represented through the multiple use of the same *background*. A background serves the function of a blank form which can be duplicated and later filled in with specific and unique information. These metaphors are in keeping with Hypercard's further organization of information into *cards*. Cards are the basic elements of information storage within stacks. They are the "nodes" of the hierarchical specifications format developed here. They may share common backgrounds, as in the case of a single, duplicated form, or they may be completely unique, as in the case of a collection of poems.

At the level of a single card, information can be divided further into *fields* as an alternative to piling it monolithically onto each card. Fields allow the author to place different types of information (all relevant to the same node) at different locations on the card. Arranged by fields, card information can then be discriminated by the reader who may be interested only in information found in a single field, for example.

Finally, perhaps the most important elements of background, card and field organization are the *buttons* which are the key to Hypercard's scripting and programming capabilities.²⁰ Buttons can set up links to other cards and stacks. They help orient the user of the system and they represent the switches that, when activated, instruct Hypercard to perform certain functions. They establish patterns in the order of information presentation that can help the user in understanding its structure.

In scripting, Hypercard cards, fields, and buttons can be programmed to manipulate data by searching, linking, sorting, marking, displaying cards, etc. In this sense, Hypercard scripts are the navigational heart of the system. They allow both the author and the reader of Hypercard cards to get to where they want to go within a series of stacks (and even between other software programs which can be accessed through Hypercard). The construction specifications format proposed here was de-

²⁰Scripting within Hypercard's programming environment involves the use of a scripting language called "Hypertalk."

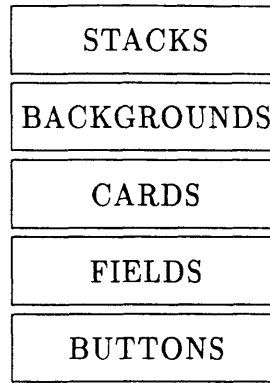


Figure 4-6: The basic elements of Hypercard (from Danny Goodman's *The Complete Hypercard 2.0 Handbook*)

veloped by writing Hypercard scripts to facilitate the establishment of relationships between specifications sections (nodes) in the writing of a specification (in conjunction with the design of a building) that will be clear in its reading later, as part of a contract for construction.

A summary of the basic elements of Hypercard introduced above, hierarchically ordered from largest to smallest subset, can be found in figure 4-6. Further information on the mechanics of Hypercard software can be found in Danny Goodman's *The Complete Hypercard 2.0 Handbook*.²¹

4.2.2 Diagrammatic Format

In the Hypercard format developed here, specification information is categorized according to the systematical order of the parts of the building being described, (in contrast to the more abstract division of information by material type and trade established by the Masterformat outline given in appendix A). It is organized in the form of a hierarchy of parts assemblies from the whole building to its schemes and components and, finally, elements. At the penultimate level of this hierarchy is a web of interdependent schematic subsystems. These are the *Foundation*, the *Superstructure*, the *Partitions*, and *Services*. A diagrammatic representation of the hypertext specification format's structure at this level, just below the building whole, is shown

²¹[11]

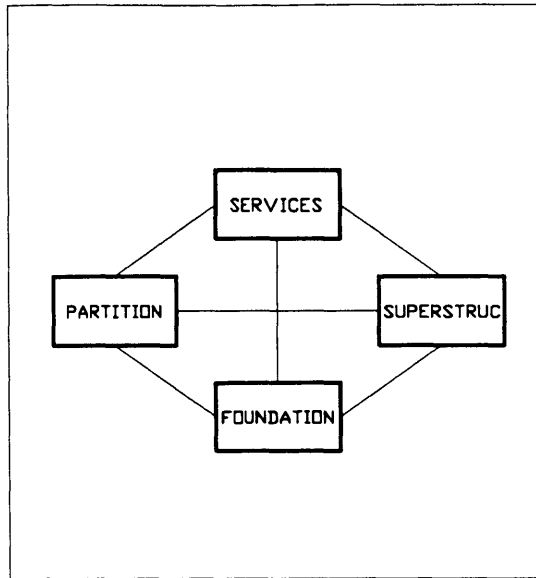


Figure 4-7: Building system structure in its most abstract form

in figure 4-7. The method of organization used throughout its further subdivision is intimately related to the actual parts of the building, the characteristics they must possess as physical objects, and the way that they are to work together.

Both the “General Conditions” of the contract for construction (Masterformat division 00) and the “General Requirements” (Masterformat division 01), though tailored to suit the unique conditions of a project with respect to labor, management, practices and procedures, are somewhat generic and only indirectly related to the actual form of the building as a physical object. They convey a different kind of information and for this reason are not included in the hierarchy of building parts specifications developed here. Rather they are seen as part of the general “groundwork” (or “boilerplate”) of the construction contract which precedes specification of the building itself.

In cases where a separate “skin” is used, conceptually distinct from the frame on which it is hung, then an additional schematic subsystem called the *envelope* subsystem may be used as is shown in figure 4-8.

In the foundation subsystem are grouped all aspects of the building’s connection to the earth (see figure 4-9). The foundation constitutes the elements of a transition between the existing conditions of the landscape and its transformed, manipu-

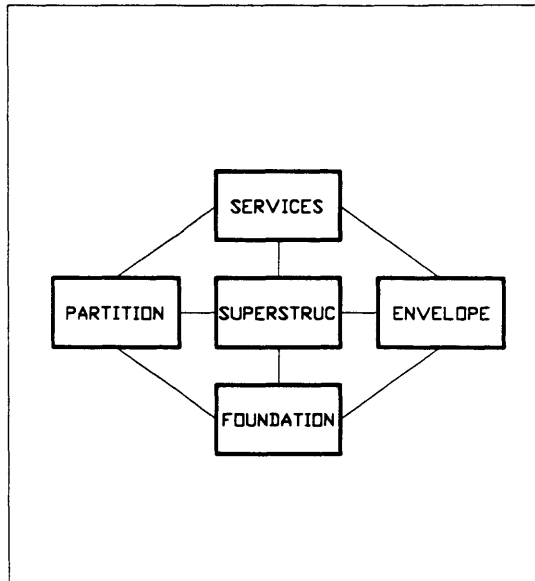


Figure 4-8: Building system structure which utilizes an independent *envelope* schematic subsystem

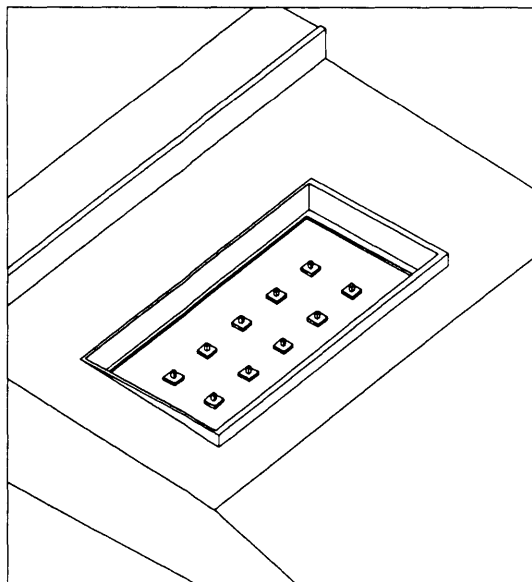


Figure 4-9: The *foundation* subsystem of a building

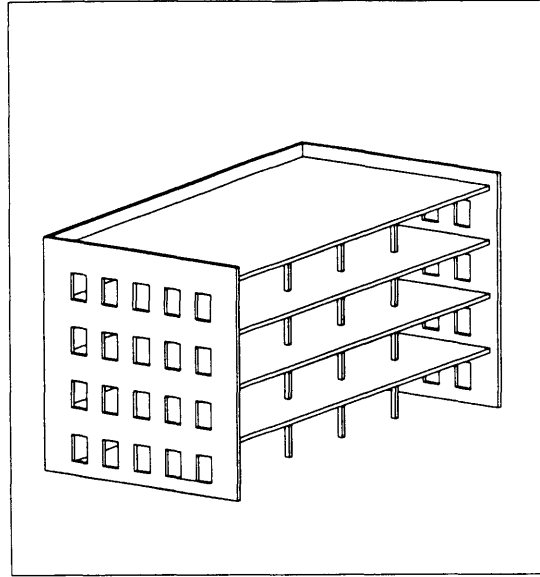


Figure 4-10: The *superstructure* subsystem of a building

lated state. These elements include not only the piles, footings and foundation walls which directly support the weight of the building's superstructure above but also the earthwork required for preparation of the substructure, roads, walks, and sitework in general.

Superstructure is the above ground load-bearing and overall space defining scheme of the building. Depicted in figure 4-10, this is the subsystem generally referred to in chapter 3's discussion of shells, boxes, and frames as the generic spatial and structural modules of building systems. Floors, walls, columns, and beams are components typically regarded as members of a building's superstructure.

Non-load-bearing components of a building structure are grouped into the partition subsystem, which includes vertical circulation, ceilings, interior doors and windows, finishes, raised floors and floor coverings in addition to the interior, non-load-bearing partition walls themselves (see figure 4-11).

Into the services category are placed the network of mechanical, electrical, plumbing, fire protection, security, and communications subsystems. Figure 4-12 gives a graphic account of the schematic structure of service components within a building system.

These four major subsystems can be thought of as the essential physical *schemes*

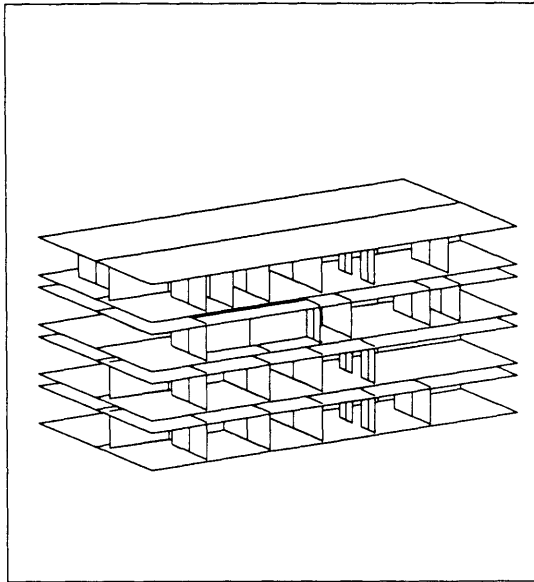


Figure 4-11: The *partition* subsystem of a building

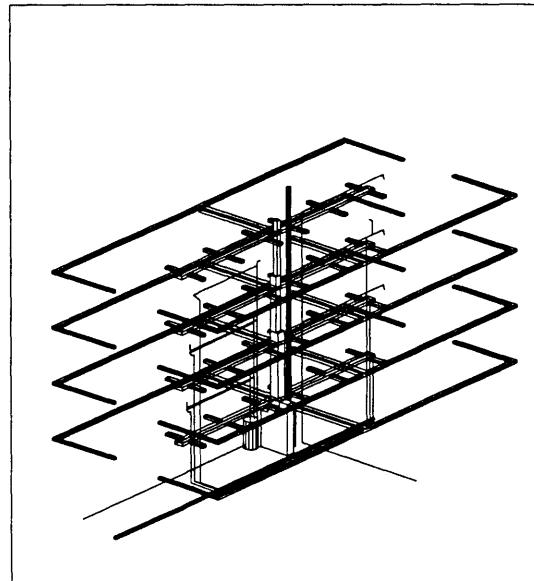


Figure 4-12: The *services* subsystem of a building

(the largest scale modular units) that go into the making of a whole building system. As the highest level within a hypertext specification system, they would appear on what is called the system *Home* card. Figure C-1 in appendix C is an image of the computer screen at this level: essentially four buttons set up in the form of a web. The buttons provide access to more detailed specification information for the schematic subsystem represented.

The webbed network of schematic subsystems shown in figure 4-7 provides a referential framework at the highest level of a building's division within which more detailed parts distinctions can now be made. For each subsystem shown in figure 4-7 (Foundation, Superstructure, Partition, Services) there exists an internal hierarchy of sub-assemblies which, connected and working together, define it in terms of its formal composition. This arrangement of parts is shown diagrammatically in figure 4-13. Note that as was discussed in subsection 3.4.1, components can be further prioritized according to "levels." The number of component levels expressed in the architectonic makeup of any building schematic subsystem (as illustrated in this kind of a chart) is roughly indicative of the "consistency" of the building: the relative gradation of its parts. In any case, the element level of the building schematic subsystem breakdown is always representative of the most fundamental objects of the building's construction. Explained in chapter 3, they are the smallest pieces that the architect and builder put together: bricks, mortar, soil, boards, metal shapes, and fasteners to name a few (see figures 3-7 and 3-8).

Imagine that, as a building whole, we are dealing with a multistory urban residential structure – a building whose program is much like that of the traditional Back Bay rowhouse investigated in chapter 3 (see figure 4-14). Unlike the rowhouses of traditional (nineteenth-century) construction, however, this version will employ a building structural system which, although inspired by the characteristic overall interactive unity of the traditional rowhouse's structural system, engages materials and assemblies available only in the fairly recent building technology. Although somewhat conjectural in its structural design, this example building has been developed with

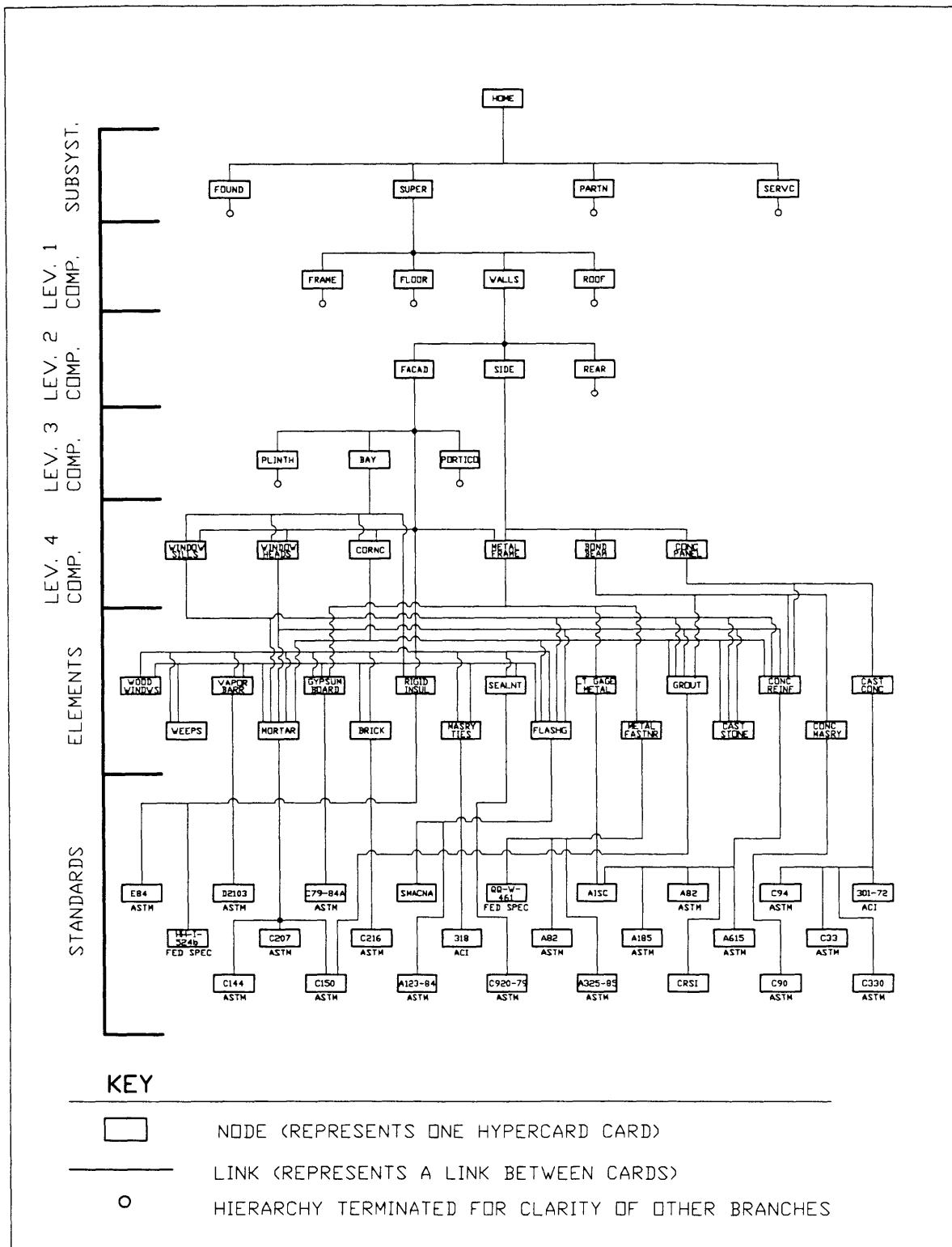


Figure 4-13: Selected branches from the "tree" hierarchy of an example hypercard specification

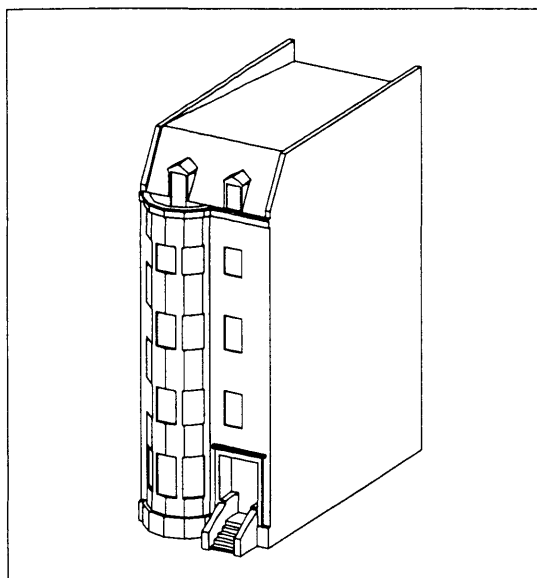


Figure 4-14: A multistory, urban, residential building as a test case for the hypertext specifications system

the subdivision and gradation of its constituent parts in mind.²² To help explain the conceptual architectonic composition of a segment of this test-case building and to further illuminate the workings of the hypertext specifications system under development I propose to begin with one of its subsystems, the superstructure, and to examine more closely several of its constituent components, namely those comprising its exterior walls, by working my way through the hierarchical organization of the system from the level of the building's largest parts to its smallest.

The building system Home card resides at the highest level within the system hierarchy as it represents the whole building as a unified organism (see figure C-1 found in appendix C). The superstructure subsystem of the contemporary rowhouse might well be depicted graphically as in figure 4-15. The Superstructure card (figure C-2 found in appendix C) appears on the computer screen when a button representing the subsystem, superstructure, is selected from the building system Home card. Card protocol (or "graphic layout") for the representation of this, subsystem, level within the hypertext system stacks (figure C-2) exhibits a scarcity of text. At this level a

²²The exterior envelope, in this case, is not conceived as a separate subsystem but as integral with the building's superstructure.

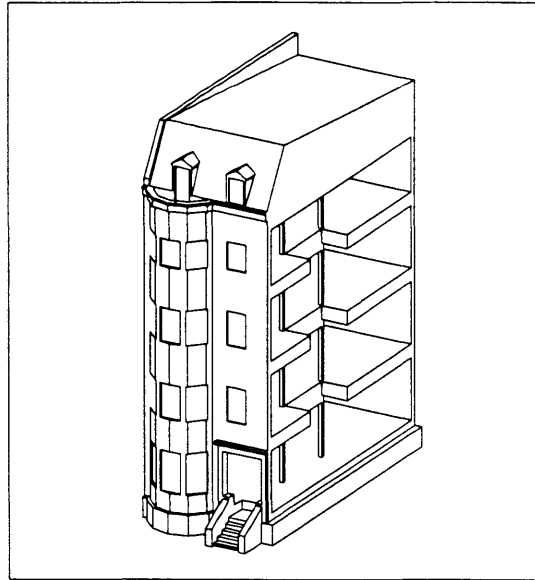


Figure 4-15: The rowhouse's *superstructure*

graphic representation of the major components relevant to the building serves the purposes of explaining their inclusion in the building while text tags giving the names of these components become the buttons by which further information about any one of them is summoned. In the upper right hand corner of the card can be found a button displaying an icon of a building. This is the system “Home” icon and it represents a direct link from the card presently on the screen back up to the highest card within the system (figure C-1 in appendix C). It is present and active on every card, allowing the user to “return home” quickly from any point within the system.

We know that each of these components can be broken down into a hierarchy of progressively lower, constituent parts levels. These levels form the individual building's *project stack* that makes up this Hypercard specifications system: Home card, subsystem cards, level 1 component cards, level 2 component cards, level 3 component cards, level 4 component cards, and element cards. The cards of an auxiliary “standards” stack are referenced throughout the main text of the project stack's cards. An abbreviated expansion of the entire superstructure system including cards from all of the levels which fall below it is given in figure 4-13. This chart can be used to orient the reader along the path I will now take into the lower reaches of the rowhouse's example building project stack. To explain the organization of data in the hypertext

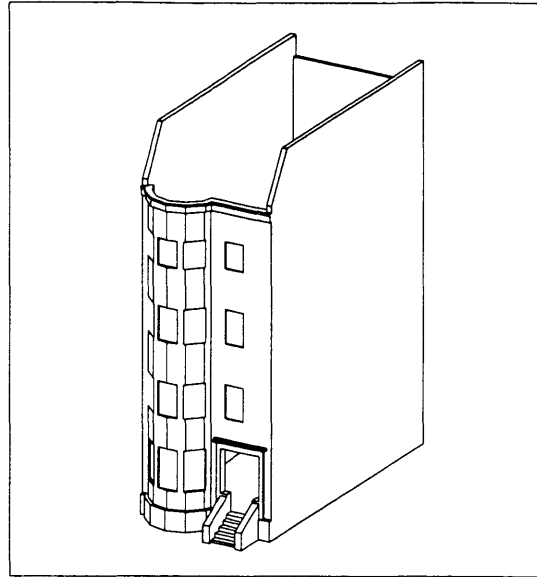


Figure 4-16: The *wallshell* level 1 component of the contemporary rowhouse

system, I will follow the path of the level 1 component “wallshell” from the superstructure subsystem card, working my way down through the layers of subordinate cards that contribute to its makeup.

The level 1 component “Wallshell” card, selected from the list of level 1 components comprising the superstructure subsystem appears on the screen as shown in figure C-3 (found in appendix C). A graphic illustration (not part of this hypertext system but included for clarification in lieu of a set of drawings of the building) is given in figure 4-16. The Wallshell card (figure C-3 in appendix C) contains a number of features that should be explained as they represent a card “background” which is more-or-less common to all component and element cards within this Hypercard application. At the upper left hand corner of the card there is a rectangular box. This box is a “field” within which is placed the name of the card currently on the screen²³ The name given to each card represents, for the system’s author and user, the most general description of the part of the building to which it refers. Note that the text field created to contain this information is small, necessitating that the card

²³I programmed Hypercard to automatically place the card’s name into this background field. Each card can be given a unique name when it is created. The name of the card then becomes a “handle” or “tag” by which it can be accessed by the program.

be named in one or, at most, two words.

To the right of the card name field are a set of four icons representing the four major building schematic subsystems used in this building. Each card has been programmed to “highlight” (reverse the image of the icon with its background, turning the background black and the image white) those icons which are relevant to the card in question. What this means is that by selecting a highlighted icon we can trace our way back up through the system hierarchy to arrive, eventually, again at the first card of the major building subsystem indicated. Selecting an icon which is *not* highlighted has no effect since there exist no connectivities (or links) between the card currently on the screen (that is to say, the component or element represented by the card) and the (non-highlighted) subsystem being selected. When a highlighted icon is selected from a card in the level 1 components stack, the system will access the corresponding subsystem card directly. At all other levels, however, the selection of a highlighted subsystem icon button will summon a “pull-down” menu containing further choices as to the path of regression desired.²⁴

Along the left hand boarder of the card are a series of buttons which link this card (and this component) horizontally, with its closest “siblings.” These represent, in this case, fellow level 1 components with which the current card’s component has some formal relationship: structurally, logically, positionally etc. The siblings of the wallshell component (as shown on its card in figure C-3 in appendix C) are the roof, frame, and floor components. Selecting any of these buttons will access the card named next to it.

In the lower left hand corner of the card is a button labelled “backtrack.” Selecting it will navigate the user back through the system in the reverse order that its cards were accessed. Further down in the system hierarchy of cards (namely in the level 4 components and the elements) there will appear in this corner of the cards several other buttons and a small text field labelled “CSI Sect.” These controls are relevant

²⁴The pull-down menu feature of this program is not original to the Hypercard software. It is a utility program called *Popup XFCN* by David Hernandez that has been made available for free public use, in this case through the Boston Computer Club’s on-line bulletin board service (Thanks to Mike Shiffer for bringing this to my attention).

to the searching and sorting features of this specification format and their functions will be covered thoroughly in section 4.2.3 of this chapter.

By far the largest portion of the level 1 component, wallshell's, card (and, for that matter, *all* component and element cards) layout is occupied by a large field containing its main body of text. This text can be thought of as the informational *substance* of its specification, written in as concise a manner as possible. Here we will find a description of any part of the building, at any level within the hierarchy of its system structure, in (quite literally the) *terms* of the smaller, constituent parts which are its subsets one level below. Interspersed within this descriptive specification of the part in question are the names of its closest offspring. These words, highlighted to indicate their status as "links" to further information, act as buttons which, when selected, access the cards for which they stand.²⁵ In this way one can always explore more detailed information relevant to the general makeup of any given component or element by following the leads indicated by highlighted text within their own description.

Pursuing one of the level 2 components listed in the main text field of the Wallshell card (by pointing the cursor over the word and clicking the mouse button) we can delve further into the hierarchy of components that contribute to the superstructure schematic subsystem of this test case hypertext application. If the front wall of the building (its "facade") is chosen, then the level 2 component card, "Facade" will appear on the screen looking like the image in figure C-4 included in appendix C. The graphic illustration shown in figure 4-17 will inform the reader of the physical scope of this component of the building while referring to figure 4-13 can help locate it within the structure of the system's conceptual hierarchy. The card protocol for level 2 components is much like that of their parents (the level 1 components) with buttons and fields placed similarly and programmed to establish links between the parts at this level of the overall structure and their "siblings," "parents," and "children" as

²⁵This procedure is accomplished in Hypercard by the program's "searching" for a match to the word selected in the text field among the card names (located in the card name field in the upper left hand corner of the card) in the rest of the stack. See section D.1 in appendix D for the exact scripting of this function.

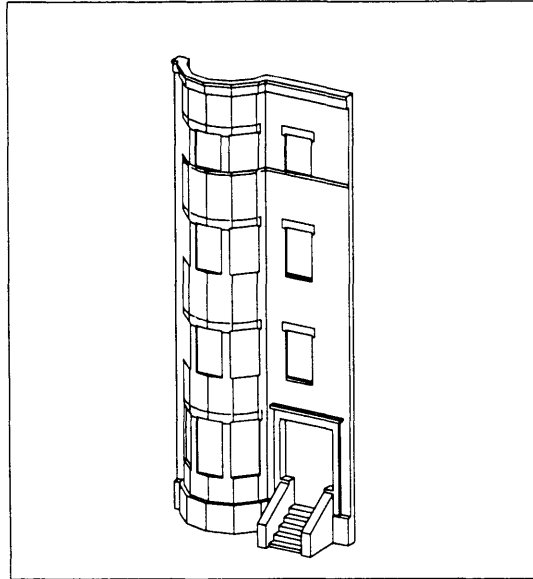


Figure 4-17: The level 2 component, *facade* of the rowhouse

appropriate to the building in question. In the main text field of this card can be found a description of the front facade component of the building in terms of its constituent elements and level 3 (or 4) component parts. The elements involved in a higher level component's makeup include those which constitute its basic fabric. In the case of the facade of the building the elements, "face brick," "metal backup framework," "mortar," "insulation," and "flashing" (among others) would be included as part of a description of its "typical" composition – the basic wall matrix ("datum" or "field") in which the lower level components (porticoes, bays, lintels, sills, jambs, pilasters, etc.) are nested. These lower level items will be encountered within the system hierarchy shortly, as we proceed through the paths of its ordered structure.

Clicking on the word "bay" in the main text field of the (level 2 component) facade card will access the level 3 component, front facade projecting Bay card. This card is depicted in figure C-5 (found in appendix C). Its pictorial image is given in figure 4-18. Similar in layout to its parent component cards, the main text field in this card can be used to access the level 4 components that are its subsets: sills, lintels, articulating pilasters and columns, bases, cornices, band courses, etc. The elements that are listed here are also those referred to in the specification of the facade wall in level 3 above. This is because the matrix that makes up the basic fabric of this

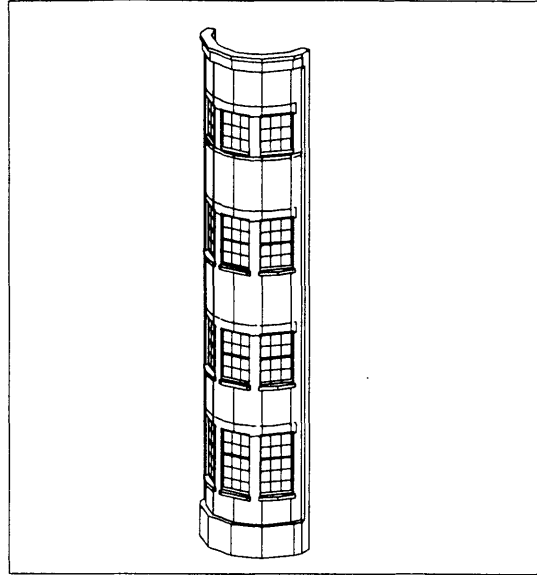


Figure 4-18: The rowhouse's front *bay* projection, a level 3 component

bay component (essentially a “typical” brick wall), is exactly the same as that of the front facade wall of which it is a part. Element cards listed multiply, as in this case, are not duplicated but merely accessed through more than one path.

Selecting the level 4 component, “cornice” will bring us to the card shown in figure C-6 (in appendix C). This component is depicted graphically in figure 4-19. The specification for the “cornice” of the “bay” projection on the front “facade” of this contemporary rowhouse structure brings us close to the end-of-the-line in this hypertext system: the most detailed level of its construction to which we need to attend as architects and builders. Although this card's layout roughly follows the pattern set by all of the component levels superior to it, the contents of its main text field can be seen to be fairly extensive while references made therein include only elements. We have now made our way through a rather dense interweaving of nested components and can finally specify the fundamental units of their assembly by summoning the element cards referred to here.

If the element, “concrete reinforcement” is selected, the card shown in figure C-7 (appendix C) would appear on the screen. Figure 4-20 shows a picture of this element in its various forms while it can also be located in terms of its position within the nearby system context by referring back to figure 4-13. The layout of element

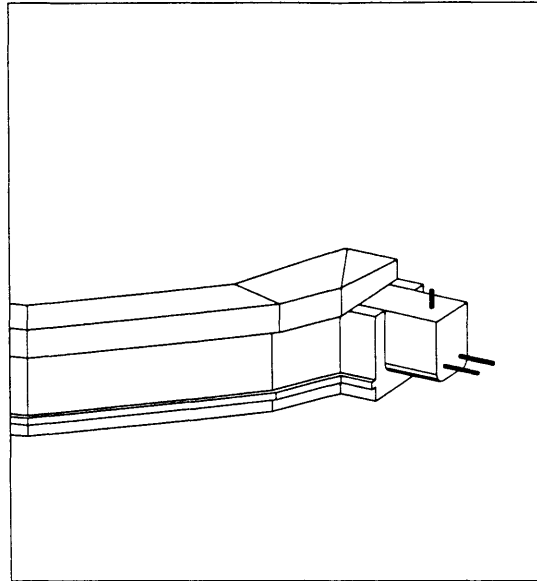


Figure 4-19: The level 4 *cornice* of the rowhouse

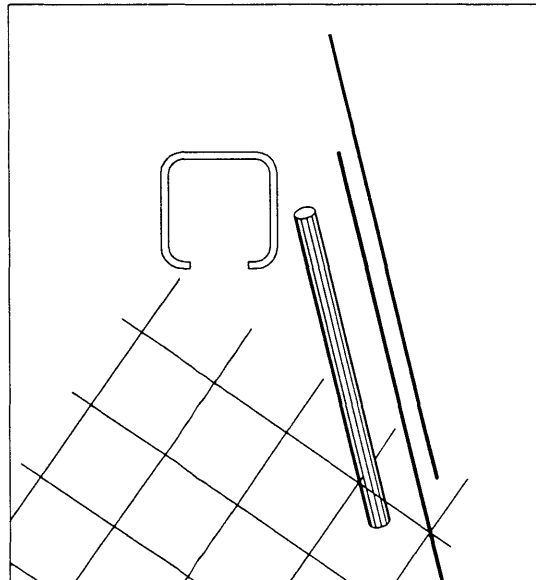


Figure 4-20: The *concrete reinforcement* element of the rowhouse structure

cards is similar to that of the components, with highlighting of the subsystem icons (located along their upper edge) being indicative of applicable system paths that lie in the pull-down menus behind. The likelihood of multiple subsystem icons being highlighted on level 4 component card and element cards is much greater than for upper level component cards because the smaller parts (those that reside at the lower levels of the parts hierarchy) are generally more common or “generic” ones. Obviously concrete reinforcement is an element of building construction with more applications throughout a building such as this one than in the cornice of a bay projection in its front facade alone! It has numerous links back up the path structure to other parts of the building – a fact which is reflected in the number of components listed in the pull-down menus which accompany the superstructure and foundation subsystem icons on this card.²⁶ The generality of element applications is evident in the character of their written specifications also, which are much more technical in terms of material properties they describe and less descriptive in terms of their constituency of other building parts (as was the case with the higher level components). Throughout the main text of element cards there are references made to standards and regulations governing their composition. This is to establish a grounding for the minimum acceptable characteristics of elements in terms of standard, more or less universally accepted criteria gathered from outside sources (sources other than the building architect or contractor): testing agencies, materials laboratories, universities, etc.

The selection of “ASTM A615” from the text field of the concrete reinforcement card brings to the screen a transcript of the applicable ASTM²⁷ standard for concrete reinforcing steel used in building construction (see figure C-8 in appendix C). Cards from the “standards” stack have a slightly different background layout than the others used in the format. Here we can see that the building schematic subsystem icons which lined the top edge of the component and element cards have been replaced with buttons which link the standard on the current card with the elements and

²⁶The pull-down menus are not shown extended in any of the card images of appendix C.

²⁷American Society for Testing and Materials, Philadelphia, PA.

components to which it *directly* applies.²⁸ Although the layout of the main text field in the standards stack is familiar, it does not contain references to any more detailed description. Related references that are included in this stack which may be of interest to a user who has accessed the present standard are noted in the boxes along the left hand edge of the card.

We have now worked our way through the entire vertical structure of the specifications system, from building whole to referenced standard providing the physical requirements for a single building element within it. Navigating our way back up through the system can now inform us about other related components of the building which use the element, concrete reinforcement as well as the front facade cornice does. From the Concrete reinforcement card, for example, we can travel back up through a different component path.

First the icon for superstructure schematic subsystem is selected, revealing a pull-down menu containing all of the possible component links between this element and any level 4 or level 3 components above. Selecting the level 4 component, “bond beam” from the superstructure pull-down menu will access the level 3 component, Bond beam card. These are the side wall beams which occur at each floor level and act as junctures between the metal floor structure, the concrete sidewall panels, and their metal back-up frame (as detailed in figure 4-21). The Bond beam Hypercard card is shown in figure C-9 (in appendix C). From the Bond beam card’s “superstructure” pull-down menu we can see that the next higher level component to which this part contributes is the sidewall itself, a level 2 component (shown graphically in figure 4-22, in card form in figure C-10 in appendix C). The absence of any level 3 component parts here indicates an inconsistency in the gradation of the fabric of the sidewalls which is perfectly reasonable since sidewalls are not visible when acting as party walls between the units of a continuous *row* of rowhouse buildings and, therefore, contain fewer levels of “nested” detail.

Sidewall components themselves are subsets of the level one component, “wall-

²⁸This is done because the material in the standards stack does not apply itself to the description of the physical composition of a whole building in the same way that the building’s actual components and elements do. Standards and testing requirements are not physical parts of the building.

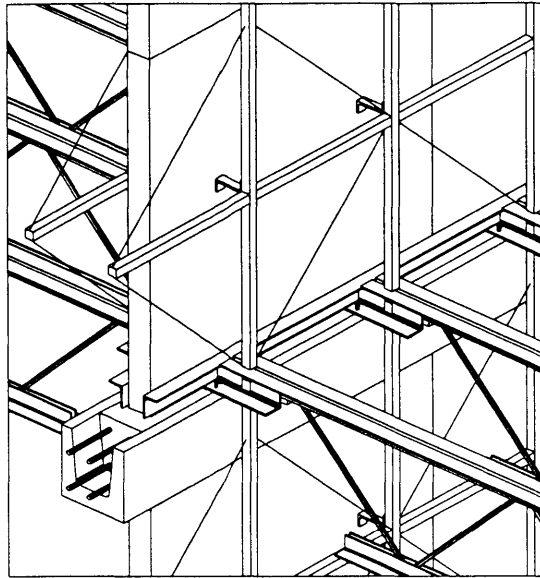


Figure 4-21: The level 4 component *bond beam* shown within the context of its application in the contemporary rowhouse at the junction of the sidewall and the metal floor framing

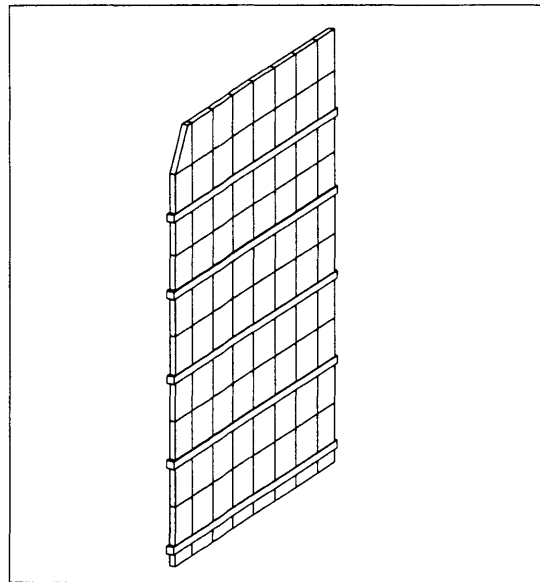


Figure 4-22: The level 2 component, *sidewall*, of the rowhouse structure

shell,” along with the front facade and rear wall of the building (see figures 4-16, and C-3 in appendix C). Continuing up beyond the wallshell card to its parent, the building superstructure (figures 4-15, C-2 in appendix C), we arrive back in the subsystem stack of this specification, only one step below its highest level: that of the Home card (figure C-1 in appendix C) and this building as a whole (figure 4-14).

We could continue to explore the makeup of this building, re-entering the structure of the hypertext specifications stacks either by backtracking over the ground just covered (by using the backtrack button located in the lower left hand corner of every card) or by selecting a different path through its components by linking through sibling, parent, or offspring card buttons presented on the cards. In doing the latter, the entire building can be described in terms of the connective interrelationships of its parts in what now can be clearly understood as a dense and multi-layered matrix of interdependent building parts.

4.2.3 Uses of the System

In the previous section I described the basic organization of the hypertext specifications system by narrating my navigation through a segment of the specification for a hypothetical rowhouse building. In so doing I followed through a series of cards linked according to the formal relationships of the building parts which they represent within an overall network: the building as a whole structural system. This process of using a computer to access a building’s specifications information is consistent with the way in which an architect conceptualizes a building in its design process (i.e., as an organic assemblage of many levels of co-dependent, nested parts) and in this sense the process of authoring such an electronic specification can aid in the design of the building. But it is by no means the only way of approaching the contents of the document. This section will explore the flexibility and convenience of the use of a computer based information management system (such as the Hypercard format for building specifications) as experienced both by the readers as well as the authors of its informational content.

It was established in section 4.2.1 that although both the reader and the writer

of a text document share a similar concern for the clear structuring of its information, they also have different interests requiring different approaches to its contents. Nowhere is this latter case more true than with the various parties involved in the reading and writing of a specifications document. If it is the building designer's concern that the integrity of the building system as an organic assemblage of mutually interrelated parts be maintained in the expression of the concept of the building then it is equally so the concern of the contractor that an accurate sense of the material types, their quantities involved, and the specific trades necessary to carry out the work of construction be also afforded. Furthermore, it is in the interest of the project's owner that an accurate "picture" of the whole building and its intended function be somehow provided in the form of an overview or summary of the anticipated work. In order to meet all of these desires and to provide additional options for the specific needs of each player on the building construction and planning team in any situation, a full integration of the computer's speed and thoroughness will have to be engaged.

Some of the features which I have built-into the Hypercard specifications formatting system developed here deal with the sorting and re-ordering of the individual cards of a whole document, allowing a tailoring of their order of access to meet the needs of individual users. Other features involve the ability to list specific subsets of cards within the stacks associated with a whole project and to navigate to one particular card directly, without having to locate it with respect to its relative location within the hierarchy (i.e., with respect to its position before, after, or adjacent to its neighboring cards). There are six distinct ways of accessing the information of the hypertext specification system developed for this thesis (and perhaps many more as it is further developed and applied in the field). These are: by hierarchical linking of cards (discussed extensively in section 4.2.2), by searching for the cards corresponding to a specific CSI Masterformat section number, by sorting the cards according to CSI Masterformat division, by parts listing according to the hierarchical "levels" they occupy within the building system, by parts listing according to one particular building subsystem, and through the listing of the names of the specific standards and testing criteria which dictate the fundamental qualities of material elements and

components used in the building's construction (and often, *indirectly*, their process of manufacture, handling, and installation).

Hierarchical Linking

One way of directly accessing the cards for related subsystems, components, elements, and their standards from anywhere within the building project's stacks is via the buttons built into the cards themselves. Buttons provide quick links to the specification for "parent," "sibling," and "offspring" parts while the option to return to the building system Home card is also available from any card. This technique was used in the basic description of the system and its means of navigation in section 4.2.2.

It may be the case, however, that a user of the system desires to access the specification for a specific part of the building, regardless of its interactive "systems" association with other adjacent, nested, or superior parts. Rather than working through the sometimes tangled paths of hierarchical parts levels and links, then, the user can turn to one of the alternative information accessing functions of this format given below.

CSI Searching

The building system Home card contains a number of buttons not yet introduced. These control the system's sorting and searching features (see figure C-1 in appendix C). Selecting the button marked "CSI Search," for example, instigates a search for cards by prompting the user to enter the specific CSI Masterformat section number that is of interest. Hypercard then checks the background field labelled "CSI Sect." located in the lower left hand corner of each component and element card within the project stack for correspondence between the numbers contained within it and the number entered by the user at the Home card. Cards with matching CSI numbers are "marked" by the computer program.²⁹ If only one match is found then the user is immediately "transported" to that card. If more than one card is found to

²⁹The "marking" of cards is Hypercard's way of remembering a select subset of cards that satisfy some user established searching criteria.

meet the search criteria then the user is informed of the number of cards that have been marked and is then presented with the first marked card.³⁰ The “Browse” arrow buttons located in the lower left hand corner of the component and element cards allow the user to then flip between the cards that have been marked.³¹ If the Masterformat section number entered by the user is not found within the components and elements of the project stack then Hypercard will return with the message: “Section *such-and-such* not found,” repeating the number for which it, unsuccessfully, searched within the message. If the information entered by the user is not found to comply with the standard pattern for CSI section numbers (see the list of Masterformat numbers in appendix A) as, for example, would a non-five-digit number or one containing non-numeric characters, then the computer will reject the request, returning with the message: “Must use 5-digit CSI number format” Only those parts cards which correspond to one of the Masterformat sections (listed in appendix A) are found in this search.

CSI Sorting

It will be remembered from the overview of conventional specifications formatting procedures given in section 4.1 that the CSI Masterformat building specification sections are grouped under larger headings called “divisions” (see appendix A). Although the basic, hierarchical arrangement of the cards within this system does not correspond to the organization of specifications sections according to the CSI divisions, Hypercard’s sorting capabilities allow for the writing of scripts to find the cards that pertain to the subjects of Masterformat’s divisions and to sort them according to the conventional

³⁰The script for the SCI Search routine written for this project is given in section D.2 of appendix D.

³¹The difference between the “Backtrack” button and the “Browse” buttons is that in browsing the user is presented only those cards within the project stack which have been specifically tagged (“marked”) by Hypercard as the result of one the search or sort operations scripted for this project. If none of these features has been used, and there are therefore no marked cards, then the message: “No cards have been marked. Mark cards by searching or sorting.” appears on the screen. The “Backtrack” button (introduced in the system description of the section 4.2.2) in contrast, will always take the user back to the card that appeared previously on the screen (hence the name, “Backtrack” and the inability to “move forward” within the stack as provided in the browse operations), whether this is leads to a marked card or not.

CSI numbering system.

Selecting the “CSI Sort” button located on the building system Home card, one is presented with the CSI Sorting card, shown in figure C-11 of appendix C. By checking the boxes located beside each division number, the user instructs Hypercard as to which sections of the whole project specification are of immediate interest. Hypercard then looks through all of the component and element cards, excluding those corresponding to sections not indicated on the CSI Sort card, marking those whose CSI number (located in the “CSI Sect.” field in the lower left hand corner of the component and element cards) does meet the search criteria set by the user, and sorting these numerically according to Masterformat number.³² As it is processing the user’s request, Hypercard informs of the number of cards found for each division selected, the total number of cards marked, and the total number of cards contained in the project specification. The user can then access the sorted cards by selecting the “Go to Cards” button whereby the first marked card (corresponding to the lowest Masterformat section number found to meet the search criteria) will appear on the screen.³³ Using the “Browse” arrow buttons on the component and element cards, the user may review the rest of the marked and sorted cards in numeric order ascending or descending according to the directional browse arrow button selected. The user may “break-out” of the sequence of numerically sorted, marked cards at any time simply by using one of the other associated parts buttons on the cards (discussed in the basic system navigation description of section 4.2.2), returning to the access of cards via their network of hierarchical links.

If no cards were found to correspond to the search and sort parameters set by the user from the CSI Sort card then Hypercard will return with the message: “No cards were found.” Two auxiliary buttons on the CSI Sort card, the “Select All” button and the “Reset All” button, allow the user to either select *all* divisions in one step or

³²Hypercard avoids confusing the cards marked in this operation with those marked in previous or subsequent operations by “unmarking” all of the cards in the project stack before it proceeds with any searching or sorting procedure. The script for this routine of the Hypercard specifications system is given in section D.3 of appendix D.

³³See the script for this feature in section D.4 of appendix D.

to de-select all divisions and start the selection process again. The “Cancel” button returns the Home card to the screen. If the user attempts to perform a sort operation where no divisions have been selected as its criteria, or if the button “Go to Cards” is selected before any sorting has taken place, then the message: “No cards have been selected” will appear.

The use of the CSI Masterformat criteria in organizing and accessing pieces of the specifications document is especially useful to general contractors and construction managers, whose charges in bidding a job for construction include the division of the work of building construction amongst the various trades that will perform it and the estimation of the material quantities needed to complete it. The sorting capabilities of the Hypercard specifications document system allow a contractor or representative of any construction trade to precisely discriminate in locating and accessing the information contained in the building specification for the purposes of materials and labor estimating and job costing and to thereby save time while becoming familiarized with the specifications for certain parts of the building in relative isolation of the others.

In exploring the hierarchical layering of the parts cards within the project stack of this specifications format, one will note that not all of the cards are given a corresponding CSI Masterformat section number. This is because the CSI section numbering system, consistent with a general trend in specifications formatting techniques being used today, addresses primarily the fundamental building trades and material types involved in conventional construction. Masterformat sections can be matched, with a fairly high degree of direct correspondence, with most of the elements and some of the level 4 components (possibly some level 3 components) of the system of parts distinction used in this thesis.³⁴ The larger assemblies involved in the makeup of a building whole (as distinguished in my own hierarchical system of parts differentiation as being subsystems, level 1, or level 2 components, especially) are, for the most part, not addressed by the CSI format.³⁵

³⁴Some of these components and elements can be assigned more than one corresponding CSI number, in which case they will be recognized as fulfilling the requirements of a hypercard search routine whose criteria include either number.

³⁵This characteristic of the conventional division of parts of a building construction project is also

Parts Listing

Another way of approaching the contents of the hypertext specification document is through a listing of the building's element and component parts with respect to their organization into "levels" (of which the building system as a whole is the highest and the building elements are the lowest). The "Parts List" button which appears on the building system Home card offers the possibility of this kind of sorting. Selecting it will summon to the screen the card shown in figure C-12 (in appendix C). Here the main categories of parts subdivision within the building's system as a whole are seen as the headings along the top row of a series of columns: the subsystem column, the level 1 through 4 components columns, and the elements column. These columns are the text fields within which Hypercard will place the names of their respective, inclusive parts. Selecting any of combination of these headings (highlighting its title) informs Hypercard for which type of part specification card to look. When the command to list the cards in the selected levels is given (by selecting the "List" button at the bottom of the the Parts List card), the computer program searches the project stack for matching headings (found within the text field of each card just above that containing its proper name), marking those that satisfy the search criteria, and returning to the Parts List card to list the results of the search under the appropriate headings.³⁶ The user is now presented with lists (on scrolling text fields) containing the members of as many of the building's hierarchical parts levels as were selected and the option to go to the marked cards. The "Go to Cards" button summons the first marked card, i.e., the first, highest level part card from the marked group, though which the others can, in the order in which they were listed, be viewed by using the "Browse" arrow buttons. If no cards have been marked, selection of the "Go to Cards" button will return with the message: "No cards have been selected." If the user wishes to view the contents of one card in particular, then clicking the mouse

reflective of its general lack of consideration for the possibility of large scale prefabrication, standardization, and componentization. This hypertext specification system can accommodate either small-parts customization or large component standardization as its organizational form takes on (or adjusts itself to) that of the building structure that it is representing.

³⁶The script for this Hypercard function is given in section D.5 of appendix D.

button with the cursor over the word on the list will summon that card regardless of its position amongst the other marked cards.³⁷ the “Select All,” the “Reset All,” and the “Cancel” buttons perform the same functions as they do on the CSI Sort card.

Sorting the cards of a building project’s hypertext specification stack is valuable to both its readers and its writers. For the writer of the specification the task should eventually become one not so much of re-writing the specifications of commonly used material elements and components (especially at the lower levels) but rather more so of simply establishing the links between them in such a way that their networked structure as represented in the computer program is reflective of certain formal aspects of the actual building being designed. Producing, at any time as the stack for a particular project is being assembled, a concise list of all the subsystems, level 1 through 4 components, (or whatever the case may be as some building applications may require fewer, some perhaps more hierarchical levels) and element cards currently included assists the writer in keeping track of which parts specifications have already been addressed. In this way (in addition to following through the network of links being established) the architect can be assured that no cards have been neglected.

For the reader of the hypertext specification information, this routine offers a narrowing down of the often vast quantity of information given in a building specification. Much like the CSI sorting function described above, the ability to sort many parts into just a few subgroups of more focused concern to the individual users of the system is a time-saver and, hopefully as well, a preventer of oversight of any aspects of the jobs to be performed in building planning and construction. Unlike the CSI method, however, this format lends itself to an increased awareness of the extent to which a building’s parts are commercially mass-produced versus designed and fabricated specially for it. The grouping of parts according to their status within an overarching structure of hierarchically related parts objects allows for a simple recognition, on the part of the architect, the component manufacturer, and the builder, of the relative expectations and responsibilities of each participant in the design and construction

³⁷The script for this procedure utilizes a Hypertalk command called “the clickText,” and is written in much the same way as that used to access offspring components, elements, and standards from within the main text field of typical parts specifications cards (as shown in section D.1 of appendix D).

team. The degree of complexity in detailed design, parts and labor estimation, parts manufacture, procurement, shipping, storage, assembly on site, testing and adjustment will depend on the level of mass-production and standardization used in the parts of the building project. This relationship can be expressed logically and clearly in the listing format of the parts included in a hypertext specification document itself.

To illustrate, consider two examples of wall system specifications in terms of their hypothetical application to the hypertext specifications format. Much can be discerned about the differences between these two specifications, and the parts that they represent, by examining their Parts List cards alone. The first wall system is a conventionally built wood stud wall. Its parts list card is shown in figure C-13 (located in appendix C). The second system uses a commercially mass-produced, standardized, prefabricated panel which forms one entire exterior wall of a building. Assembling four such prefabricated panels forms a complete wallshell component. Its parts list card is shown in figure C-14 (located in appendix C). By grading the parts of construction assembly of each of these systems according to their relative status within the hierarchy of an overall building in the format of the parts list, the Hypercard format gives an immediate indication of what are the critical levels of parts specifications in each of these systems, especially for the building's designer, its parts manufacturer, and its builder.

For the traditional wood frame construction, the architect is responsible for the selection and "architectural" treatment of every part within the subsystem, from its largest component (the level 4 wallshell) down to its most fundamental elements (the type of wood studs and sheathing to be used and the types of fasteners used to attach them). Beyond the elemental level the architect relies on the promises of the manufacturers of these raw materials for assurance that the parts will meet or exceed their advertised standards. The architect's personal charge for the proper application of every detail, involving many small, elemental pieces of the building is typical of the traditional role of the building planner or designer. This concern for the small parts and individual details is evidenced in the traditional wood frame wall construction's specification as they tend to fill up the lower component and element categories of the

parts list. Like the architect in this case, the builder must consider the characteristics of all of the individual materials (mainly elements) purchased for the job. Since they will probably come from a variety of sources (different distributors and suppliers), attention must be paid to their compatibility within larger, site-built components. In addition, however, he must accurately estimate the material quantity and labor requirements of the job, taking into account the likelihood of material breakage on-site and the storage of sufficient stock as well as the labor issues of hiring and layoffs, labor skill level, and union affiliation of each mason, framer, drywall hanger, roofer, insulator, sider, finish carpenter, plumber, electrician, and painter.

In the case of the mass-produced panels, the architect must be concerned with the selection of appropriate panel type and their configuration within the building meeting all programmed performance requirements for its most efficient use after completion. The architect's specification of this subsystem essentially stops with its level 3 components, beyond which the panels' standard specification, put out by the unit's manufacturer is relied upon. This is where the main concerns of the manufacturer begin. It is the manufacturer's responsibility to see that the prefabrication and assembly of the many smaller parts that go into the overall unit meet the expectations and standards set by the company's promotional literature and standard product specification. As for the prefabricated project's on-site builder (as opposed to its builders in the factory as well as the builders of the traditional framed wall subsystem), the issue of foremost concern shifts from the transformation of small elements into individually crafted components by skilled labor on site, to the acquisition, storage, handling, and proper fastening of larger components around whose modular constraints the building has been designed. This often requires large cranes and moving machinery and lots of open space for their negotiation but less so the use of traditional, highly skilled craftsmen.

Where the traditional construction process involves a potpourri of skilled, semi-skilled and unskilled, specialists and generalist tradesmen, laborers and suppliers, the process of large prefabricated component assembly requires much more centrally controlled activities, involving the craning, adjusting and precise fixing into place of

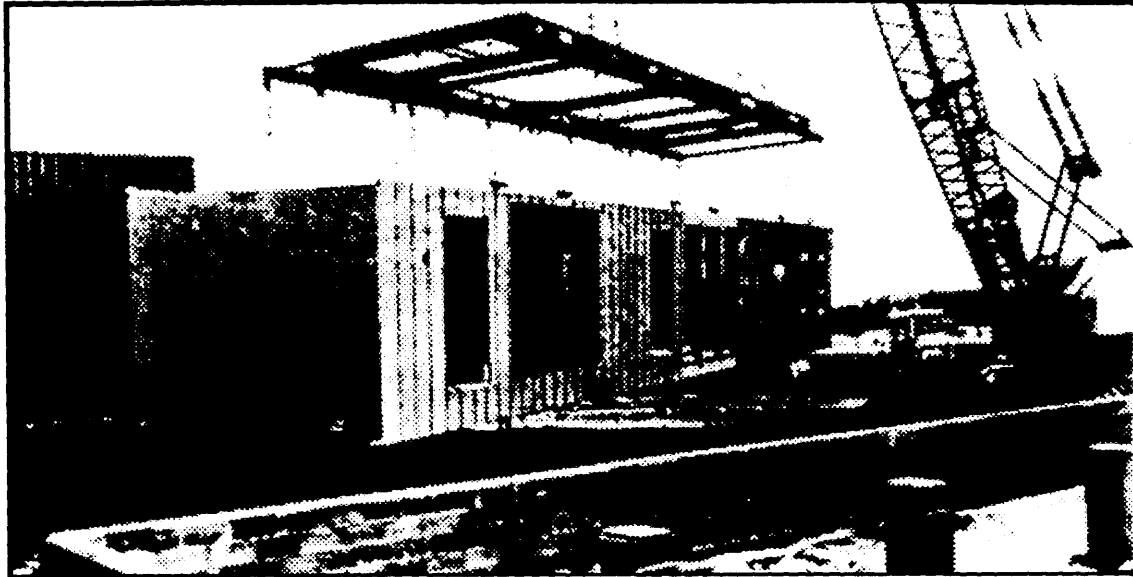


Figure 4-23: The craning into place of a large scale building element which is at once a structural scheme (from Richard Bender's *A Crack in the Rear View Mirror*)

prefinished units of construction, often requiring no further work on site other than this installation (see figure 4-23). The ready availability of some very large scale, industrialized building parts pushes the notion of parts categorization established in section 3.2 to an extreme. Because they meet the criteria of standardized mass-production and commercial availability, for example, mobile homes can be thought of as elements of construction. At the same time they can represent independent, three-dimensional habitable units, thereby qualifying as schemes! Interpretation in this situation would depend on the particular context in which such units were used.

Intrinsic to the hypertext specifications system described in this thesis is the potential of readily adjusting the numbers, the informational content, and the linked structure of the cards within a building project stack to meet the unique demands of either the “elemental,” on site craftsmanship characteristic of traditional construction means, the prefabrication and erection of large scale, “high-level” building components, typical of industrialized construction, or the many techniques for building construction used today which combine certain aspects of both of these extremes. Whatever strategy is used, its relative status is reflected in the results of the computer software’s parts listing routine.

Subsystems Listing

Related to the parts listing routine is a listing function that allows the user to specify the parts level of one specific building subsystem that is of interest. Figure C-15 (appendix C) shows the card for this purpose, looking very much like the Parts List card. They work in similar ways as well. With the Subsystems List card, however, one is allowed to specify only one subsystem under which cards are to be listed. Beneath the subsystems column heading on the subsystems listing card can be found a pull-down menu that lists the subsystems from which the user may select. In this case the list includes the schematic subsystems: foundation, superstructure, partition, and services. Further refinement can be made in the range of the search by indicating which levels of the scheme's cards are to be listed. This is carried out in the same way that parts levels were selected on the Parts List card: by highlighting the rectangular parts level titles which head each parts level column. With the subsystem and appropriate parts levels indicated, one can instigate a search through all of the cards in the building stack simply by selecting the "Sort" button located along the bottom of the card.

Hypercard will go to the building stack and mark all cards that meet the criteria of the search set by the user, returning to the Subsystems List card to report the names of the cards found under their appropriate parts level column, and keeping track of the total number of cards found.³⁸ Cards that meet the search criteria are identified by their satisfaction of two conditions. The first is that they are relevant to the subsystem selected for the search. This condition is met if and only if the corresponding subsystem icon located along the top of every part specification card is highlighted, indicating that the part on that card belongs, either directly or indirectly, to that particular subsystem of the building. The second condition is that they belong to one of the parts levels, components or elements, which were highlighted by the user as being of interest in the range of the sort. This condition is met if the parts level indication, located at the upper left hand corner of each card, corresponds to one of

³⁸The script for this operation can be found in section D.6 of appendix D.

those chosen in the Subsystems List card.

After the sort is complete the user may either go to the first marked card of the stack by selecting the "Go to Cards" button, or access any single card in the list directly by simply clicking the mouse with the cursor over the name of the card desired. Once that card appears on the screen, all of the other listed cards can be accessed (in the order in which they were listed) relative to the card present on the screen, by using the "Browse" button located in its lower left hand corner. One can also visit cards individually in any order by selecting one directly from the list on the Subsystems List card, viewing the card, returning to the Subsystems List card by using the "Backtrack" button, and then selecting any other card, visiting that card and returning to the Subsystems List card, etc. The Subsystems List card is especially useful for narrowing down the range of cards that may be of immediate interest for a particular purpose.

Standards Listing

The standards listing feature of this format performs much like the parts list except that instead of a listing of the physical parts-objects which are specified for inclusion in a particular building, the standards list produces an inventory of the standards and testing criteria which are to ultimately control the physical properties of the parts. Although not typically written by the building designer or owner, the project's standards are clearly referenced throughout most contemporary building specifications. The ability of the computer to handle large databases makes this kind of reference more than just a reminder of further, more detailed, reading to be found in other documents. It can facilitate the immediate, on-screen access of the actual document so referenced. Here, at the Standards Listing card of this Hypercard computer specifications application, one can obtain a list of all the standards referred to throughout the text of the specification by selecting the "List" button at the bottom of the card (see figure C-16 found in appendix C). Clicking on the names of the standards within the list will summon their text information individually while selecting the "Go To Cards" button will reveal the first standards card with the inherent potential to

continue “browsing” through the entire stack of standards applicable to this project (sequentially forward or backward as they appear on the list) by using the “Browse Stds” arrow buttons located familiarly in the lower left hand corner of the standards cards. Since the standards cards inhabit a stack all their own, the listing routine is a fairly simple one (see the script in section D.7 of appendix D) while the individual card retrieval option (by selecting the name of any standard from the list) functions in much the same way that the corresponding operation in the Parts List function does.

System Use in Professional Practice

The most important advantage gained from the application of hypermedia to the production of building construction documents is the increased ability to fashion the organization of the specifications text according to the conceptualization of the actual building to which its information refers –a translation of the building’s *form*, in so far as it implies a “systems” behavior of the intended final product, into a medium through which it can be effectively communicated. It is this kind of parts-relating activity, and not the accounting of abstract material and labor type, that reinforces the building’s design idea both in its support of the design process as one involving the exploration of conceptual interrelationships between material objects and their systems medium, and in its presentation of relevant information to the constructors of the building.

For the builder, the advantages of a computer based specifications document are many. The information organization, sorting, searching and retrieving capabilities of one particular system have been touched upon in this chapter. The elimination of the constrictions (and material waste) of paper based documentation is now being accelerated by the ready availability and economy of high-performance, compact computer technology. Contractors, materials suppliers, and tradesmen, using lap-top computers can now access information in the field electronically as they work. The increased use of modems and large scale data-handling networks has established the necessary links required for information access from any location, on-line, and in real-time. Changes

in the contract for construction, which in the past have taken days or even weeks to be negotiated, processed, recorded, printed and distributed, can, with the aid of a common electronic database for contract documentation, be carried out almost instantaneously, thus reducing the likelihood of error due to miscommunication or lack of timely communication.

Since the format of the hypertext specification is consistent with the parts of the building and their interconnections (and thereby, of construction as an assembly of parts), contractors and tradesmen can more easily come to an understanding of their own individual portion of the work of construction with respect to its impacts on that of others around them. This emphasis on the physical interrelationships of the parts of a building also promises to strengthen the bond of communication between craftsmen of diverse trades through their common interest in the end of a singular building object.

At the same time, individual participants in the process of building construction can organize the bulk of the specification information by reducing it down to that which is most relevant to a particular task: A material supplier can look at the specification according to the involvement of one particular material type within the building (as far as that material type is reflected in the Masterformat divisions and sections—see appendix A). A component prefabricator may be interested in sorting the specification information by levels. A heating contractor might want to discriminate the specification information by subsystem. A manufacturer of specialty building elements may want to scan the stack for only those cards corresponding to a specific Masterformat section number. A steel fabricator could quickly check the specification for any and all standards, codes, and regulations that will impact his production of parts for the job.

Many more criteria for the organization of cards could be implemented by programming with the relatively simple Hypercard scripting language that was used for all of the features described above. At some point, of course, the great diversity of ways of accessing information becomes more of a liability than an asset. This happens when the great variety of ways of using the system obscure any last vestiges of

its fundamental and primary form of organization. The card protocol, being overrun with buttons, fields, and special codes, become difficult to read – “the forest being obscured by the trees,” so-to-speak. The Hypercard stacks developed for this thesis contain cards that were designed to maintain some semblance of a clean, uncluttered appearance, relegating searching and sorting features to their own separate cards (in their own separate stack, in fact). The cards still, however, have to bear all of the fields and button and codes that relate each part of the building to its place within the hierarchy of parts and assemblies of the overall building system. This card protocol is what gives to the specification its inherent order amidst the many ways of *re-ordering* them. The order that permeates each individual card and thus the format of the specification as a whole is the order of the building system hierarchy itself. Inherent in the hypertext specification format is the relationship, therefore, not only of *part-to-part*, but also of *part-to-whole*. It is in this sense that the essential, holistic quality of the building can be addressed in words, even in term of its smallest pieces.

Chapter 5

Conclusion: A View to the Whole

The specifications format developed in the previous chapter diverges from an established convention that has otherwise been largely unchallenged in the North American building construction industry. This divergence is not simply the result of another computer application for architects and builders. On the contrary, given the flexibility of the hypertext processing of specifications data, it could easily have been organized according the CSI section numbering system directly while allowing for the sorting and re-ordering of the cards in any order desired. Certainly this would have involved a less complex network of card linking. The notion of a card level hierarchy would not be necessary as all parts, materials, and processes in the Masterformat system are listed as hierarchically equal.

The hypertext specifications format developed here is based on an argument for specifications writing and reading “from the ground up” so-to-speak, beginning with an understanding of how we experience architecture and thus how we interpret buildings as holistic systems whose *idea* can be recorded and communicated. The importance of understanding the *concept* of a building was emphasized with the notion that the systematic aspects of a building can be clarified during its design phase, before it is actually built. In order to improve a building as a system, it is necessary to view its parts in terms of the transformations that they undergo from individual, relatively independent objects, into a single, useful, and much more profound whole.

From such an understanding of what a building is can one then determine the ap-

appropriate roles of each part, separating them conceptually for the purpose of analysis and quantification. In other words, an understanding of the whole is prerequisite to an adequate understanding of the parts that make it up. This is why one cannot expect that an adequate understanding of a building, much less any suggestion toward its improvement, can arise out of a representational format which communicates only list-like information or, worse yet, information not about the building-to-be at all but about certain conventional, methodological procedures that must be followed by those who work on it. The leap from an understanding of the building as a whole system to an understanding of some of its constituent parts is an intuitive and natural one. But to go in the other direction is much more difficult. The conceptual assembly of an effective whole building system from a given set of discrete and independent available elements requires all of the insight that the architect can offer, and even more effort to make this insight intelligible and thus available to others. At the same time, such an effort is in the direct interest of the building's coherence as a unified object.

The specifications format developed in this thesis takes pains to translate into an easily readable language the intimate relationship between a building and its parts, because this relationship is so fundamental to the proper working of the whole thing. This relationship is also something that everyone can understand intuitively from their everyday experiences. To “get to the point” of architecture, however, is to “see” beyond the immediacy of the senses, while maintaining the importance of sense experience as a common basis for shared understanding. Philosopher Josef Pieper writes:

Man is certainly in a position not only to know things, but also to understand the relationship between things and his concept of them. In other words, over and above his spontaneous perception of things, he can have knowledge by means of judgments and reflections. To put it another way, human knowledge may not only be true, it can also be knowledge of the truth.¹

¹[19, p. 58]

At the heart of this striving for knowledge is the desire to identify the interrelationships of things at progressively higher levels of unification –to identify the systems phenomenon in the parts of a larger whole and in so doing to come to know the *essence* of the whole. Christopher Alexander comments:

The system viewpoint is a modern, disciplined version of the sense of wonder. It is that view of things which man takes when he becomes aware of oneness and wholeness in the world.²

All knowledge begins with amazement of the apparent coherence of things, complete knowledge of which we do not possess. The approach to understanding buildings as systems advocated in this thesis can help us to approach *the point* of a building – what it really *is* –even before we are clear as to what its every detail should be. How, specifically, does the approach strengthen our overall understanding of a building? The following is a summary of six benefits to be gained from the intrinsic orientation of the systems approach.

1. It suggests that we become conscious of the *level* of our investigation into any part of the building, always with reference to the whole building.
2. It suggests that we pay attention not to the parts per se but also to their interconnections, thus establishing an understanding of both the spatial and logical relationships which lie at the heart of the system.
3. It reveals unanticipated aspects of the form of the whole and of its parts that can contribute to a more complete understanding of the characteristics of both.
4. It elucidates the intimate relationship that exists in a building system between shape and behavior at all levels of parts and the level of the whole building, thus suggesting the idea of the *unification* of form.
5. It encourages the exercise of *naming* as conducive to good design and construction process. By means of language we can address a wall as a wall, reflecting

²[2]

our conception of it as one thing even though it is composed of parts which themselves are made up of parts that can also, at lower levels of parts differentiation, be addressed as singular entities as well. Naming is part of the individuating concept of the parts of architecture, reinforcing the intimate relationship between what we call a part, what it is, and how it can contribute to a larger assembly.

6. It suggests the stringing together of names and connecting words into larger statements that describe the characteristics of the larger assembly which their combination makes. It involves an already known language of abstraction which is capable of establishing a formal framework that models itself after perceived reality. Links between simple terms can help us to link simple, fundamental ideas into more complex associations, fostering more comprehensive comprehension.

These six points can be categorized into issues of the parts/whole (points number 1 and 2), issues of form (points number 3 and 4), and issues of language (points number 5 and 6). A brief summary statement on each of these topics is presented in the subsections below.

The Importance of the Parts

This paper has argued for an emphasis on issues of *substance* over those of *procedure*. The systems approach to buildings aims at an understanding of *what* a building is and, implicitly, *how* it is so over and above the primarily administrative concerns of *when* the task of its making should be carried out and by *whom*. Administrative concerns should be implied in the substance of the building and not take precedence over it since a building survives the way that it was made.

If one extreme of the substance/procedure dichotomy is an overriding emphasis on the administration of the design and construction process then the other extreme is a focus on the physical parts objects alone as the “stuff” of which a building is made. Industrialized building construction has bequeathed to us what is now a profusion

of parts objects about which we are told anything and everything is known. This implication for the industrialization of architecture and building is that a designer need merely *choose* which parts to use in a building, adding up their costs to make sure that the total falls within budget.

To what extent, then, are we *really* interested in the parts of a building? Certainly not much at all on the terms of industrialized architecture given above. Rather, a focus on the physical parts of a building as the *substance* of its making is fruitful only to the extent that the parts reinforce the overall design concept of the whole, relating to it through various scales of reference, from the level of the smallest element to the largest components and schemes. In so doing the parts become *parts of a system*. “Selecting” a skylight unit, for example, as an element for a proposed new building is only the beginning of a process whose success depends on the degree to which the building designer can make it work within the context of the building’s system. This larger task involves the acquisition of a thorough understanding of the interface of this particular part to those around it and the careful consideration of how its behavior both affects and is affected by the overall form of the building system. Remember that a system is comprised not solely of things but more properly of things whose interdependent behavior is relevant to the resultant useful characteristics of the larger assemblies that they create.

The Unity of Form

Reading systems in buildings involves a way of looking at things and their interrelationships precisely with an eye to their forms. To understand why a building is the way it is, one must explore its form as based on the perceived systematic behavior of the forms of its parts. “Form” as “shape” is not very interesting to architects who see their constructions as material, labor, affordance, behavior, memory, and association, all integrated in sense perception. This notion of the unity of form entails a necessarily strong relationship between *perception* and *conception*. To accept the unity of form is to affirm that the appearance, physical composition, behavior, and meaning of a thing are integral aspects of what it is. Though they can be conceived of

and analyzed as distinct characteristics, they cannot be isolated from a real material object in practice. A change in one of these characteristics produces a change in all of the others and the whole thing. To speak of the form of something is to speak of its essence.

The Role of Language

Verbal communication is perhaps the most direct form of representation that we have at our disposal. Language involves a pre-determined system of its own that is patterned after the systems that we perceive in direct sense experience. In communicating verbal ideas about a building system we come as close as possible to a perceptual experience of it without actually being there. Drawing, of course, can record and communicate information about the spatial, geometrical characteristics of a building but written or spoken language can address performance and behavioral aspects as well as spatial ones. The implication of spatial relationships in written construction specifications can be achieved in a number of ways, some of which are listed below:

1. Spatial relationships between parts can be expressed in the referencing of blocks of text one to another, indicating the inclusion of one thing within something larger and the composition of any single part as a set of smaller, constituent parts in an implied, hierarchical classification.
2. Within descriptive text itself, language can be used to displace objects relative to others. Words like *above*, *beside*, *below*, *attached to*, *within* are examples of prepositions that imply a spatial organization to the objects they connect. Here, the classification of joints into monolithic, articulated, and mediated types can further specify the quality of the spatial relationships between the parts they link.
3. Spatial relationships between parts can also be represented in text purely in terms of the visual composition of words that are presented to the reader. The way that words are arranged on a page, and the way they are treated in terms

of typeface and punctuation, can mirror the spatial arrangement of parts within a building.

Behavioral and performance characteristics of a building system are easily recorded in verbal or textual media simply by describing what a thing does or must do. While it is not the intention of the specifications format developed in chapter 4 that graphic media be superseded by written media, the near complete exclusion of pictures from the prototype specification document served the purpose of investigating just how far the text document could go in conveying all aspects of the form of a building. Integration of text and image in the form of drawings tends to favor the graphic media and relegate the textual to a role of subservience. The hypertext experiment in this thesis attempts to reverse this tendency, if only for the purposes of pushing writing to its greatest communicative capabilities. The capabilities of writing, in terms of the most complete expression of form and system, exceed those of drawing. While writing has been most fully explored within the domains of poetry and lyric, only a fraction of its potential has been exercised in so-called “technical writing.”

Because the networks and hierarchies of parts organized within a building system are non-linear, multidimensional, dynamical constructs, however, it has proved difficult to represent anything like the full extent of their patterns of interconnection in a textual medium with any clear sense of the overall spatial order, especially on the static, printed page. In traditional print, a building could be described in terms of its progressive levels of parts hierarchy only with a great deal of repetition since many aspects of its overall characteristics would have to be included again in the description of parts at lower, more detailed levels. The efficacy of graphic media in representing systems aspects of a building results from its almost exclusive concentration on spatial relationships and on the conventional expectation in drawing that the same thing should be shown from more than one spatial point of view. Hence we commonly draw elevations that depict objects also shown in plan but from a different angle. Repetition of information and information approached from more than one “point of view” in written media, on the other hand, is tedious and typically thought of as inefficient or redundant.

Hypertext has revealed new possibilities for the written representation of form, allowing for the flexibility of multiple vantage points on the same information without the inefficiency of writing or storing the same thing more than once. With hypertext a system “overview” can be clearly represented as integrated within a more detailed account of the parts which are nested within it. The Hypercard specifications format introduced in chapter 4 embodies this organizational relationship. The computer and its software in this example, although facilitating the representation of this relationship, are not necessary to it. They are simply a convenient application of technology toward the improved communication of something that has always existed. The computer is not used here as a “decision maker” or as an “intelligent” resource toward a methodology of design. Rather it is a tool to bring the readers and writers of a construction specification closer to an understanding of what is the common goal of their efforts. At the same time, allowing multiple readings of the same document caters to the specific needs of both readers and writers.

Though most people think of graphic images when they think of the communication of architectural ideas, architects also rely heavily on verbal and written media for the conveyance of building form. This reliance promises only to increase in the future as larger numbers of specialists, who are taught literary skills and not graphic ones, become involved in an increasingly verbose and legalistic construction industry. It behooves us as architects to accept the importance of the spoken and especially the written word, to speak in terms that are understandable to others but also to clarify in our message our own concept of the coherence of a building system. Verbal communication helps us to perform our design craft better by bringing us conceptually closer to the actual buildings of which we speak. Language and representation can help bring *conception* into closer accord with *perception*.

This thesis’ investigation of buildings as systems and their effective communication in written construction specifications aims to strengthen our abilities as architects and builders to focus upon the task at hand while avoiding the mistake of taking symbols for that which they symbolize or taking the parts for the whole. It has attempted to broaden the conceptual picture of the essence of architectural construct and to

suggest means for manipulating this picture in representational terms that are as close in keeping with the final product being represented as is possible.

As in the reading of text, the reading of architecture involves a process which subordinates itself to a larger product. In “reading” architecture the conceptual synthesis that is required to integrate many interdependent, temporal, perceptual experiences is analogous to the physical synthesis that makes of many individual physical parts of a building a physical system. I believe that both the building systems model and the specifications format patterned after it, developed in this thesis, can be built upon and refined in future work toward a better understanding of what is the essence of architecture.

Appendix A

CSI Masterformat List of Section Titles and Numbers

SPECIFICATIONS¹

DIVISION 1 – GENERAL REQUIREMENTS

01010	SUMMARY OF WORK
01020	ALLOWANCES
01025	MEASUREMENT AND PAYMENT
01030	ALTERNATES/ALTERNATIVES
01040	COORDINATION
01050	FIELD ENGINEERING
01060	REGULATORY REQUIREMENTS
01070	ABBREVIATIONS AND SYMBOLS
01080	IDENTIFICATION SYSTEMS
01090	REFERENCE STANDARDS
01100	SPECIAL PROJECT PROCEDURES
01200	PROJECT MEETINGS
01300	SUBMITTALS
01400	QUALITY CONTROL
01500	CONSTRUCTION FACILITIES AND TEMPORARY CONTROLS
01600	MATERIAL AND EQUIPMENT
01650	STARTING OF SYSTEMS/COMMISSIONING
01700	CONTRACT CLOSEOUT
01800	MAINTENANCE

DIVISION 2 – SITEWORK

02010	SUBSURFACE INVESTIGATION
02050	DEMOLITION
02100	SITE PREPARATION
02140	DEWATERING
02150	SHORING AND UNDERPINNING
02160	EXCAVATION SUPPORT SYSTEMS
02170	COFFERDAMS
02200	EARTHWORK
02300	TUNNELING
02350	PILES AND CAISSONS
02450	RAILROAD WORK

¹[7] Masterformat is a registered trademark of The Construction Specifications Institute, Inc. (CSI) and Construction Specifications Canada (CSC). Masterformat Division and Section numbers and titles are also found in CSI Document MP-2-1, 1988 edition. Masterformat is used here with the permission of CSI, Alexandria, VA.

02480 MARINE WORK
02500 PAVING AND SURFACING
02600 PIPED UTILITY MATERIALS
02700 SEWERAGE AND DRAINAGE
02760 RESTORATION OF UNDERGROUND PIPELINES
02770 PONDS AND RESERVOIRS
02780 POWER AND COMMUNICATIONS
02800 SITE IMPROVEMENTS
02900 LANDSCAPING

DIVISION 3 - CONCRETE

03100 CONCRETE FORMWORK
03200 CONCRETE REINFORCEMENT
03250 CONCRETE ACCESSORIES
03300 CAST-IN-PLACE CONCRETE
03370 CONCRETE CURING
03400 PRECAST CONCRETE
03500 CEMENTITIOUS DECKS
03600 GROUT
03700 CONCRETE RESTORATION AND CLEANING
03800 MASS CONCRETE

DIVISION 4 - MASONRY

04100 MORTAR
04150 MASONRY ACCESSORIES
04200 UNIT MASONRY
04400 STONE
04500 MASONRY RESTORATION AND CLEANING
04550 REFRACTORIES
04600 CORROSION RESISTANT MASONRY

DIVISION 5 - METALS

05010 METAL MATERIALS
05030 METAL FINISHES
05050 METAL FASTENING
05100 STRUCTURAL METAL FRAMING
05200 METAL JOISTS
05300 METAL DECKING
05400 COLD-FORMED METAL FRAMING
05500 METAL FABRICATIONS
05580 SHEET METAL FABRICATIONS
05700 ORNAMENTAL METAL
05800 EXPANSION CONTROL
05900 HYDRAULIC STRUCTURES

DIVISION 6 - WOOD AND PLASTICS

06050 FASTENERS AND ADHESIVES
06100 ROUGH CARPENTRY
06130 HEAVY TIMBER CONSTRUCTION
06150 WOOD-METAL SYSTEMS
06170 PREFABRICATED STRUCTURAL WOOD
06200 FINISH CARPENTRY
06300 WOOD TREATMENT
06400 ARCHITECTURAL WOODWORK
06500 PREFABRICATED STRUCTURAL PLASTICS
06600 PLASTIC FABRICATIONS

DIVISION 7 - THERMAL AND MOISTURE PROTECTION

07100 WATERPROOFING
07150 DAMPPROOFING
07190 VAPOR AND AIR RETARDERS
07200 INSULATION
07250 FIREPROOFING

07300 SHINGLES AND ROOFING TILES
07400 PREFORMED ROOFING AND CLADDING/SIDING
07500 MEMBRANE ROOFING
07570 TRAFFIC TOPPING
07600 FLASHING AND SHEET METAL
07700 ROOF SPECIALTIES AND ACCESSORIES
07800 SKYLIGHTS
07900 JOINT SEALERS

DIVISION 8 - DOORS AND WINDOWS

08100 METAL DOORS AND FRAMES
08200 WOOD AND PLASTIC DOORS
08250 DOOR OPENING ASSEMBLIES
08300 SPECIAL DOORS
08400 ENTRANCES AND STOREFRONTS
08500 METAL WINDOWS
08600 WOOD AND PLASTIC WINDOWS
08650 SPECIAL WINDOWS
08700 HARDWARE
08800 GLAZING
08900 GLAZED CURTAIN WALLS

DIVISION 9 - FINISHES

09101 METAL SUPPORT SYSTEMS
09200 LATH AND PLASTER
09230 AGGREGATE COATINGS
09250 GYPSUM BOARD
09300 TILE
09400 TERRAZZO
09500 ACOUSTICAL TREATMENT
09540 SPECIAL SURFACES
09550 WOOD FLOORING
09600 STONE FLOORING
09630 UNIT MASONRY FLOORING
09650 RESILIENT FLOORING
09680 CARPET
09700 SPECIAL FLOORING
09780 FLOOR TREATMENT
09800 SPECIAL COATINGS
09900 PAINTING
09950 WALL COVERINGS

DIVISION 10 - SPECIALTIES

10100 CHALKBOARDS AND TACKBOARDS
10150 COMPARTMENTS AND CUBICLES
10200 LOUVERS AND VENTS
10240 GRILLES AND SCREENS
10250 SERVICE WALL SYSTEMS
10260 WALL AND CORNER GUARDS
10270 ACCESS FLOORING
10280 SPECIALTY MODULES
10290 PEST CONTROL
10300 FIREPLACES AND STOVES
10340 PREFABRICATED EXTERIOR SPECIALTIES
10350 FLAGPOLES
10400 IDENTIFYING DEVICES
10450 PEDESTRIAN CONTROL DEVICES
10500 LOCKERS
10520 FIRE PROTECTION SPECIALTIES
10530 PROTECTIVE COVERS
10550 POSTAL SPECIALTIES
10600 PARTITIONS
10650 OPERABLE PARTITIONS
10670 STORAGE SHELVING
10700 EXTERIOR SUN CONTROL DEVICES

10750 TELEPHONE SPECIALTIES
10800 TOILET AND BATH ACCESSORIES
10880 SCALES
10900 WARDROBE AND CLOSET SPECIALTIES

DIVISION 11 - EQUIPMENT

11010 MAINTENANCE EQUIPMENT
11020 SECURITY AND VAULT EQUIPMENT
11030 TELLER AND SERVICE EQUIPMENT
11040 ECCLESIASTICAL EQUIPMENT
11050 LIBRARY EQUIPMENT
11060 THEATER AND STAGE EQUIPMENT
11070 INSTRUMENTAL EQUIPMENT
11080 REGISTRATION EQUIPMENT
11090 CHECKROOM EQUIPMENT
11100 MERCANTILE EQUIPMENT
11110 COMMERCIAL LAUNDRY AND DRY CLEANING EQUIPMENT
11120 VENDING EQUIPMENT
11130 AUDIO-VISUAL EQUIPMENT
11140 SERVICE STATION EQUIPMENT
11150 PARKING CONTROL EQUIPMENT
11160 LOADING DOCK EQUIPMENT
11170 SOLID WASTE HANDLING EQUIPMENT
11190 DETENTION EQUIPMENT
11200 WATER SUPPLY AND TREATMENT EQUIPMENT
11280 HYDRAULIC GATES AND VALVES
11300 FLUID WASTE TREATMENT AND DISPOSAL EQUIPMENT
11400 FOOD SERVICE EQUIPMENT
11450 RESIDENTIAL EQUIPMENT
11460 UNIT KITCHENS
11470 DARKROOM EQUIPMENT
11480 ATHLETIC, RECREATIONAL AND THERAPEUTIC EQUIPMENT
11500 INDUSTRIAL AND PROCESS EQUIPMENT
11600 LABORATORY EQUIPMENT
11650 PLANETARIUM EQUIPMENT
11660 OBSERVATORY EQUIPMENT
11700 MEDICAL EQUIPMENT
11780 MORTUARY EQUIPMENT
11850 NAVIGATION EQUIPMENT

DIVISION 12 - FURNISHINGS

12050 FABRICS
12100 ARTWORK
12300 MANUFACTURED CASEWORK
12500 WINDOW TREATMENT
12600 FURNITURE AND ACCESSORIES
12670 RUGS AND MATS
12700 MULTIPLE SEATING
12800 INTERIOR PLANTS AND PLANTERS

DIVISION 13 - SPECIAL CONSTRUCTION

13010 AIR SUPPORTED STRUCTURES
13020 INTEGRATED ASSEMBLIES
13030 SPECIAL PURPOSE ROOMS
13080 SOUND, VIBRATION AND SEISMIC CONTROL
13090 RADIATION PROTECTION
13100 NUCLEAR REACTORS
13120 PRE-ENGINEERED STRUCTURES
13150 POOLS
13160 ICE RINKS
13170 KENNELS AND ANIMAL SHELTERS
13180 SITE CONSTRUCTED INCINERATORS
13200 LIQUID AND GAS STORAGE TANKS
13220 FILTER UNDERDRAINS AND MEDIA
13230 DIGESTION TANK COVERS AND APPURTENANCES

13240 OXYGENATED SYSTEMS
13260 SLUDGE CONDITIONING SYSTEMS
13300 UTILITY CONTROL SYSTEMS
13400 INDUSTRIAL AND PROCESS CONTROL SYSTEMS
13500 RECORDING INSTRUMENTATION
13550 TRANSPORTATION CONTROL INSTRUMENTATION
13600 SOLAR ENERGY SYSTEMS
13700 WIND ENERGY SYSTEMS
13800 BUILDING AUTOMATION SYSTEMS
13900 FIRE SUPPRESSION AND SUPERVISORY SYSTEMS

DIVISION 14 - CONVEYING SYSTEMS

14100 DUMBWAITERS
14200 ELEVATORS
14300 MOVING STAIRS AND WALKS
14400 LIFTS
14500 MATERIAL HANDLING SYSTEMS
14600 HOISTS AND CRANES
14700 TURNTABLES
14800 SCAFFOLDING
14900 TRANSPORTATION SYSTEMS

DIVISION 15 - MECHANICAL

15050 BASIC MECHANICAL MATERIALS AND METHODS
15250 MECHANICAL INSULATION
15300 FIRE PROTECTION
15400 PLUMBING
15500 HEATING, VENTILATING, AND AIR-CONDITIONING (HVAC)
15550 HEAT GENERATION
15650 REFRIGERATION
15750 HEAT TRANSFER
15850 AIR HANDLING
15880 AIR DISTRIBUTION
15950 CONTROLS
15990 TESTING, ADJUSTING, AND BALANCING

DIVISION 16 - ELECTRICAL

16050 BASIC ELECTRICAL MATERIALS AND METHODS
16200 POWER GENERATION
16300 HIGH VOLTAGE DISTRIBUTION (Above 600-Volt)
16400 SERVICE AND DISTRIBUTION (600-Volt and Below)
16500 LIGHTING
16600 SPECIAL SYSTEMS
16700 COMMUNICATIONS
16850 ELECTRIC RESISTANCE HEATING
16900 CONTROLS
16950 TESTING

Appendix B

Example of a Conventional Specifications Section

SECTION 03200¹

CONCRETE REINFORCEMENT

PART 1 – GENERAL

1.1 SUMMARY

- A. Provide concrete reinforcement where shown on the Drawings, as specified herein, and as needed for a complete and proper installation.
- B. Related Work:
 - 1. Documents affecting work of this section include, but are not necessarily limited to, General Conditions, Supplementary Conditions, and Sections in Division 1 of these Specifications.
 - 2. Section 03100: Concrete formwork.
 - 3. Section 03300: Cast-in-place concrete.

1.2 SUBMITTALS

- A. Comply with pertinent provisions of Section 01340.
- B. Product data: Within 35 calendar days after the Contractor has received the Owner's Notice to Proceed, submit:
 - 1. Materials list of items proposed to be provided under this section;
 - 2. Manufacturer's specifications and other data needed to prove compliance with the specified requirements;
 - 3. Shop Drawings showing details of bars, anchors, and other items, if any, provided under this Section.

¹From an example by Hans Meier ([16]).

1.3 QUALITY ASSURANCE

- A. Use adequate numbers of skilled workers who are thoroughly trained and experienced in the necessary crafts and who are completely familiar with the specified requirements of this Section.
- B. Comply with pertinent provisions of the following, except as may be modified herein.
 - 1. ACI 318;
 - 2. CRSI "Manual of Standard Practice."

1.4 DELIVERY, STORAGE, AND HANDLING

- A. Comply with pertinent provisions of Section 01620.
- B. Delivery and storage:
 - 1. Use necessary precautions to maintain identification after bundles have been broken.
 - 2. Store in a manner to prevent excessive rusting and fouling with dirt, grease, and other bond-breaking coatings.

PART 2 – PRODUCTS

2.1 REINFORCEMENT MATERIALS AND ACCESSORIES

- A. Bars:
 - 1. Provide deformed billet steel bars complying with ASTM A615, using grades shown on the Drawings.
 - 2. Where grades are not shown on the Drawings, use grade 60.
- B. Steel Wire:
 - 1. Comply with ASTM A82.
 - 2. For tie wire, comply with Fed Spec QQ-W-461, annealed steel, black, 16 gauge minimum.
- C. Welded wire fabric:
 - 1. Provide welded steel, complying with ASTM A185.
- D. Welding electrodes:
 - 1. Comply with AWS A5.1, low hydrogen, E70 series.
- E. Bolsters, chairs, spacers, and other devices for spacing, supporting, and fastening reinforcement in place:
 - 1. Use wire bar type supports complying with CRSI recommendations, unless otherwise shown on the Drawings.
 - 2. Do not use wood, brick, or other non-complying material.
 - 3. For slabs on grade, use supports with sand plates or horizontal runners where base material will not support chair legs.

4. For exposed to view concrete surfaces, where legs of supports are in contact with forms, provide supports with either hot-dip galvanized or plastic-protected legs.

2.2 FABRICATION

A. General:

1. Fabricate reinforcing bars to conform to the required shapes and dimensions, with fabrication tolerances complying with the CRSI Manual.
2. In case of fabricating errors, do not straighten or rebend reinforcement in a manner that will weaken or injure the material.
3. Reinforcement with any of the following defects will not be acceptable.
 - a. Bar lengths, depths, and/or bends exceeding the specified fabrication tolerances;
 - b. Bends and kinks not shown on the Drawings;
 - c. Bars with reduced cross-section due to excessive rusting or other cause.

PART 3 – EXECUTION

3.1 SURFACE CONDITIONS

- A. Examine the areas and conditions under which work of this Section will be performed. Correct conditions detrimental to timely and proper completion of the Work. Do not proceed until unsatisfactory conditions are corrected.

3.2 INSTALLATION

A. General:

1. Comply with the specified standards for detail and method of placing reinforcement and supports, except as may be modified herein.
 2. Clean reinforcement to remove loose rust and mill scale, earth, and other materials which reduce or destroy bond with concrete.
 3. Position, support, and secure reinforcement against displacement by formwork, construction, and concrete placing operations.
 4. Locate and support reinforcement by metal chairs, runners, bolsters, spacers, and hangers, as required.
 5. Place reinforcement to obtain minimum coverages for concrete protection.
 6. Arrange, space, and securely tie bars and bar supports together with the specified tie wire.
 7. Set wire ties so twisted ends are directed away from exposed concrete surfaces.
- B. Install welded wire fabric in as long lengths as practicable, lapping adjoining pieces at least one full mesh.
 - C. Provide sufficient numbers of supports, and of strength to carry the

reinforcement.

- D. Do not place reinforcing bars more than 2" beyond last leg of any continuous bar support.
- E. Do not use supports as bases for runways for concrete conveying equipment and similar construction loads.

3.3 SPLICES

- A. Lap splices:
 - 1. Tie securely with the specified wire to prevent displacement of splices during placement of concrete.
- B. Splice devices:
 - 1. Obtain the Architect's approval prior to using splice devices.
 - 2. Install in accordance with manufacturer's written instructions.
 - 3. Splice in a manner developing at least 125% of the yielding strength of the bar.
- C. Welding:
 - 1. Perform in accordance with AWS D1.4-79.
- D. Do not splice bars except at locations shown on the Drawings, except as otherwise specifically approved by the Architect.

3.4 TESTING

- A. Samples:
 - 1. Samples for physical tests of reinforcement will consist of at least two pieces, each 18" long, of each size of reinforcement steel, selected by the testing agency from material at the building site or at the fabricator's or supplier's yard.
 - 2. Material to be sampled at the building site shall have been delivered thereto at least 72 hours before it is needed.
- B. Tests:
 - 1. Where samples are taken from bundles as delivered from the mill, with the bundles identified as to heat number, and provided mill analyses accompany the report, then one tensile test and one bend test will be made from a specimen of each ten tons or fraction thereof of each size of reinforcement steel.
 - 2. Where positive identification of the heat number cannot be made, or where random samples are taken, then one series of tests will be made from each 2-1/2 tons or fraction thereof of each size of reinforcement steel.
 - 3. Payment for testing is described in Section 01410 of these Specifications.

END OF SECTION

Appendix C

Hypercard Card Illustrations

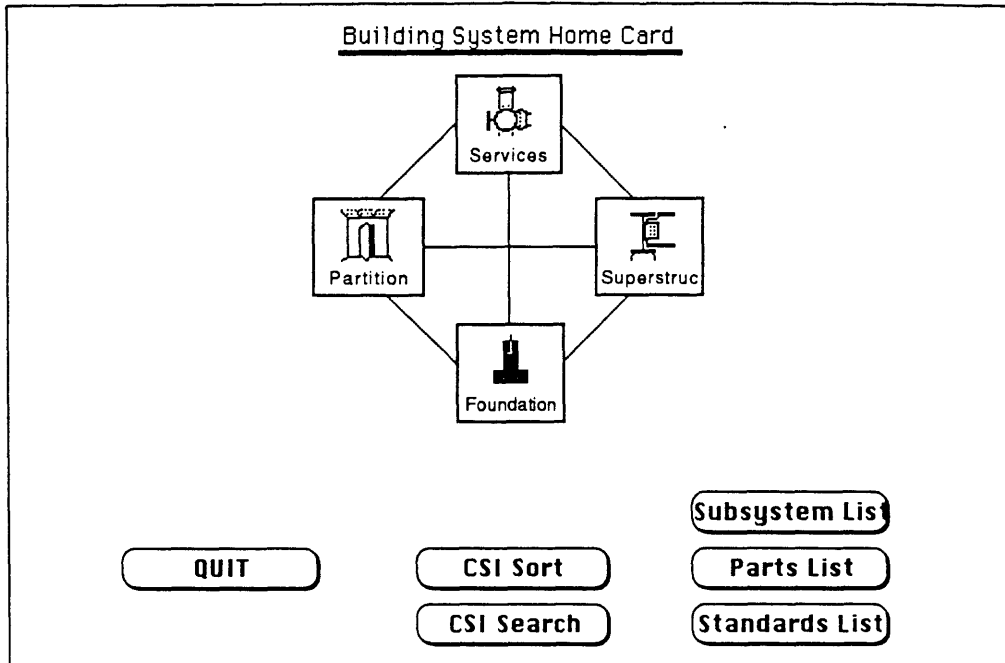


Figure C-1: Building system Home card

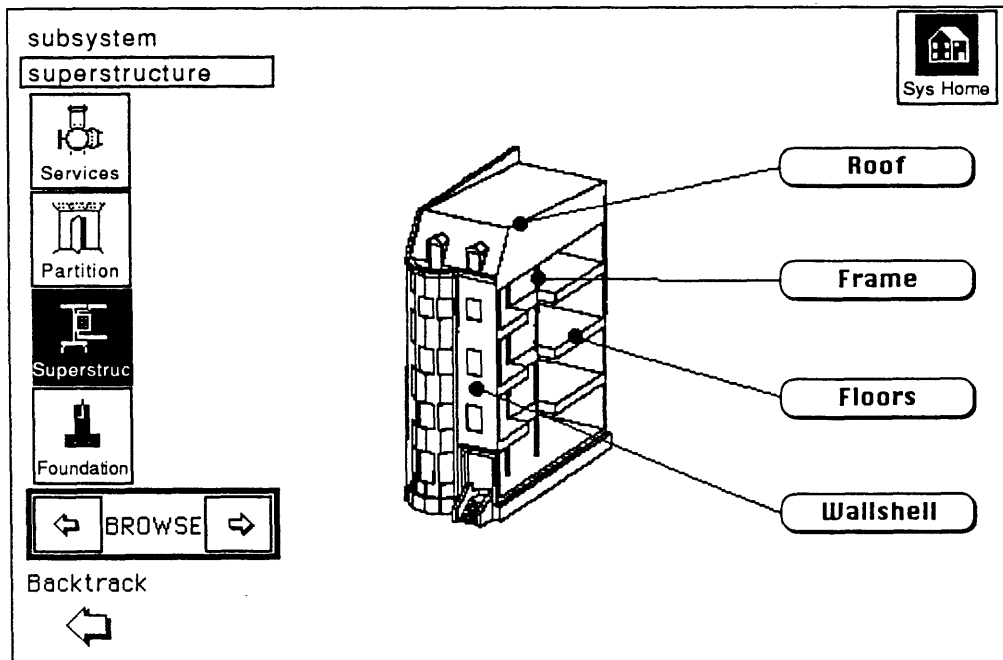


Figure C-2: Superstructure card

LEVEL 1 COMPONENT: wallshell	Partition	Services	Superstruc	Foundation	Sys Home
<input type="checkbox"/> roof <input type="checkbox"/> frame <input type="checkbox"/> floors <input type="checkbox"/> substruct <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	<p>WALLSHELL</p> <p>GENERAL REQUIREMENTS: Provide an exterior wall shell for the building according to a rectangular geometry having dimensions to the outside face of the masonry veneer wall and the centerline of the precast concrete party walls between rowhouse units of 20 feet wide by 40 feet in depth from the setback on the main street side to the back alley. The height of the wallshell shall be 55 feet from existing grade to top of parapet.</p> <p>Join facade to sidewalls monolithically along their vertical edges by interlacing the brick masonry veneer of the facade with the ends of the concrete panels that make up the dividing wall between</p>				
<input type="button" value="←"/> BROWSE <input type="button" value="→"/> Backtrack 					

Figure C-3: Wallshell card

LEVEL 2 COMPONENT: facade	Partition	Services	Superstruc	Foundation	Sys Home
<input type="checkbox"/> rearwall <input type="checkbox"/> sidewalls <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	<p>cavity between the outside face of the gypsum sheathing and the inside face of the brick wythe, free of mortar drippings and other debris. Adhere 2" of extruded polystyrene rigid insulation board continuously over the outside face of the gypsum sheathing still leaving at least an inch of clear cavity between the insulation and the brick. Provide weep holes at 4' o.c. at the base of all masonry walls and just above any lintel or header. Use corrosion resistant metal flashing to divert moisture away from the gypsum backup wall surface and toward the weeps. Provide one rectangular window opening at each floor level along the right hand side of the building. Use steel shelf angle (4-1/2" x 6" x 1/4") for headers supporting brick above door and porch openings. Above main windows in facade use cast stone window heads.</p>				
<input type="button" value="←"/> BROWSE <input type="button" value="→"/> Backtrack 					

Figure C-4: Facade card

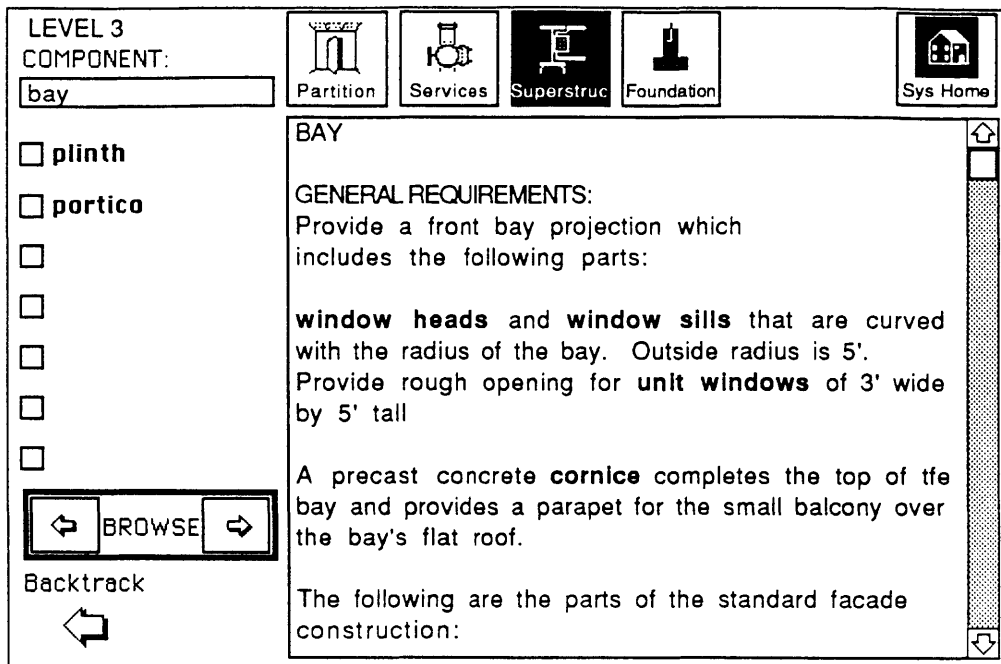


Figure C-5: Bay card

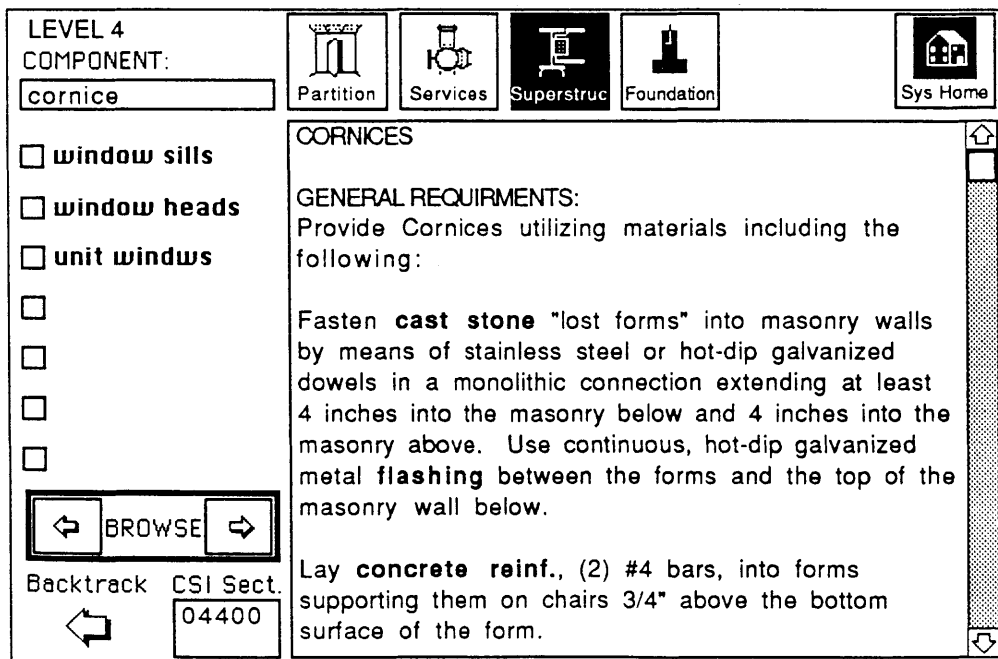


Figure C-6: Cornice card

ELEMENT						
concrete reinf.		Partition	Services	Superstruc	Foundation	Sys Home
<input type="checkbox"/> cast concrete <input type="checkbox"/> conc. forms <input type="checkbox"/> conc. masonry <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>		CONCRETE REINFORCEMENT GENERAL REQUIREMENTS: Comply with the recommendations of the CRSI Manual. BARS: Provide billet steel bars complying with ASTM A615 . Where grades are not shown on the Drawings, use grade 60. SPLICING DEVICES: Obtain Architect's approval prior to using splicing devices. STEEL WIRE: Steel wire shall comply with ASTM A82 . Tie wire				<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>
<input type="button" value="←"/> BROWSE <input type="button" value="→"/>						
Backtrack <input type="button" value="←"/>		CSI Sect. 03200				

Figure C-7: Concrete reinforcement card

Standard:		<input type="checkbox"/> conc. reinf.	<input type="checkbox"/>	<input type="checkbox"/>	
A615		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Sys Home
<input type="checkbox"/> ASTM A82 <input type="checkbox"/> CRSI Manual <input type="checkbox"/> QQ-W-461 <input type="checkbox"/> A185 <input type="checkbox"/> ACI 318 <input type="checkbox"/> <input type="checkbox"/>		ASTM A615 - 86 Standard Specification for Steel Reinforcement for Structural Concrete. 1. SCOPE 1.1 This specification covers deformed and plain billet-steel concrete-reinforcement bars. A deformed bar is defined as a bar that is intended for use as reinforcement in reinforced concrete construction. The surface of the bar is provided with lugs or protrusions (herein-after called deformations) which inhibit longitudinal movement of the bar relative to the concrete which surrounds the bar in such construction and conform to the provisions of this specification. The standard sizes			<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>
<input type="button" value="←"/> BROWSE <input type="button" value="→"/>					
Backtrack <input type="button" value="←"/>		STDS			

Figure C-8: ASTM A615 card

LEVEL 4 COMPONENT: bond beam	Partition	Services	Superstruc	Foundation	Sys Home
<input type="checkbox"/> bar joists <input type="checkbox"/> conc. panel <input type="checkbox"/> metal frame <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	<p>BOND BEAMS</p> <p>GENERAL REQUIREMENTS: Provide bond beams of precast concrete, unit masonry forms, cast concrete, mortar, grout, and reinforcement as per the standard practices of the National Concrete Masonry Institute.</p> <p>Use unit concrete masonry bond beam forms and concrete reinf. by way of (2) #4 bars running continuously with the length of the beam. The forms shall be filled with grout to the top, vibrated and screeded.</p> <p>No coatings or repellents shall be used as a finish for the bond beams.</p>				
<input type="button" value="←"/> BROWSE <input type="button" value="→"/> Backtrack CSI Sect. <input type="button" value="←"/> 04220					

Figure C-9: Bond beam card

LEVEL 2 COMPONENT: sidewalls	Partition	Services	Superstruc	Foundation	Sys Home
<input type="checkbox"/> facade <input type="checkbox"/> rearwall <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	<p>SIDEWALL</p> <p>GENERAL REQUIREMENTS: Provide building sidewalls using the following components:</p> <p>concrete panel units with dimensions 5' x 5' x 5" thick stacked two high between floors. A reinforced concrete horizontal bond beam at each floor separates the concrete panels and provides a ledge on which the floor joists bear. A light gage metal frame stabilizes the concrete panel wall on either side.</p> <p>rigid insulation is used on the inside face of the metal frame for sound insulation.</p>				
<input type="button" value="←"/> BROWSE <input type="button" value="→"/> Backtrack <input type="button" value="←"/>					

Figure C-10: Sidewall card

Total number of cards selected	30
Total number of cards	52

	<u>* of cards</u>		<u>* of cards</u>
<input checked="" type="checkbox"/> Division 01	0	<input checked="" type="checkbox"/> Division 09	1
<input checked="" type="checkbox"/> Division 02	2	<input checked="" type="checkbox"/> Division 10	0
<input checked="" type="checkbox"/> Division 03	5	<input checked="" type="checkbox"/> Division 11	0
<input checked="" type="checkbox"/> Division 04	8	<input type="checkbox"/> Division 12	
<input checked="" type="checkbox"/> Division 05	7	<input type="checkbox"/> Division 13	
<input type="checkbox"/> Division 06		<input checked="" type="checkbox"/> Division 14	0
<input checked="" type="checkbox"/> Division 07	6	<input checked="" type="checkbox"/> Division 15	0
<input checked="" type="checkbox"/> Division 08	1	<input checked="" type="checkbox"/> Division 16	0

Figure C-11: CSI sorting card

Number of cards selected						52
Total number of cards						52

SUBSYSTEMS						LEU 1 COMP.	LEU 2 COMP.	LEU 3 COMP.	LEU 4 COMP.	ELEMENTS
foundation	↑ floors	↑ earthwork	↑ bay	↑ bond beam	↑ anchor bolts					
partition	frame	facade	plinth	concrete pane	bar joists					
services	roof	foundn wall	portico	cornice	cast concrete					
superstructur	sitework	grade beam		metal frame	cast stone					
	substructure	pilecap		window heads	conc. formwo					
	wallshell	piles		window sills	concrete mase					
		rearwall			concrete reinf					
		sidewalls			face brick					
					flashing					
					grout					
					gypsum board					
					It gage mtl					
					masonry ties					
					metal fastene					
					mortar					
					precast concre					
					rigid insulation					
					sealant					

CARD LISTING ROUTINE

Figure C-12: Parts listing card

CONVENTIONAL WOOD FRAME WALL					
SUBSYSTEMS	LEU 1 COMP.	LEU 2 COMP.	LEU 3 COMP.	LEU 4 COMP.	ELEMENTS
superstruct	↑ wallshell roof floors	↑ front wall rear wall side wall 1 sidewall 2	↑ front portico cupola dormers wd chimn. enc gable end	↑ ridge vent soffit vent windows ext. doors gutters downspouts turned wd colt railing ext. steps	↑ framing lumbe steel nails galv nails const. adhesv osb decking insulation siding gypsum wallbo air infil barr polyeth sheet paint/stain mtl flashing sill seal ext. trim pres. treated joist hangers bolts,screws door hrdwr
	↓	↓	↓	↓	↓

Figure C-13: Parts listing card shown for a conventional, site-built house

PREFABRICATED WOOD WALL PANEL					
SUBSYSTEMS	LEU 1 COMP.	LEU 2 COMP.	LEU 3 COMP.	LEU 4 COMP.	ELEMENTS
superstruct	↑ wallshell roof floors	↑	↑	↑	↑ wall panel roof panel floor panel chimney portico cupola dormer shims fasteners
	↓	↓	↓	↓	↓

Figure C-14: Parts listing card shown for a house made from a kit of stock, prefabricated panels

Select Here	Number of cards selected	38
	Total number of cards	41

SUBSYSTEMS	LEU 1 COMP.	LEU 2 COMP.	LEU 3 COMP.	LEU 4 COMP.	ELEMENTS
Superstruc	floors frame roof wallshell	facade rearwall sidewalls		bond beam concrete pane cornice metal frame window heads window sills	anchor bolts bar joists cast concrete cast stone conc. formwo concrete mase concrete reinf face brick flashing grout gypsum board lt gage mtl masonry ties metal fastene mortar precast concre rigid insulation sealant

SUBSYSTEM LISTING ROUTINE

Figure C-15: Subsystem listing card

Total number of cards	25
-----------------------------	----

STANDARDS LISTING ROUTINE

301-72
318
A123-84
A185
A325-85
A446
A615
A82
AISC
C144
C150
C207
C216
C33

Figure C-16: Standards listing card

Appendix D

Hypercard Scripts

D.1 ClickText Script

```
on mouseUp
  lock screen
  find the clickText in field "card name"
  if field "card name" contains the clickText
  then
  else
    unmark all cards
    mark this card
    go to stack "standardstack"
    find the clickText in field id 35
    if field id 35 contains the clickText
    then
      unmark all cards
      mark this card
      go to the first marked card of stack "hyperspec"
      unmark this card
      go to the first marked card of stack "standardstack"
      unmark this card
      unlock screen
    else
      go back
      unlock screen
    end if
  end if
  unlock screen
end mouseUp
```

D.2 CSI Search Script

```
on mouseUp
  ask "Type Masterformat narrowscope Section"
  if it is "" then
  else
    put It into p
    if p > 1 and p < 14999 then
      lock screen
      put 2 into y
      push card
      pop card into k
      set lockMessages to true
      go to stack "hyperspec"
      unmark all cards
      mark all cards where background field "CSI" contains p
      put the number of marked cards into d
      go to card "homer" of stack "bldgsys home"
      unlock screen
      if d = 0
      then
        answer "section number" && p && "not found"
      else
        if d = 1
        then
          go to the first marked card of stack "hyperspec"
        else
          answer ""&& d && "cards found."
          go to first marked card of stack "hyperspec"
        end if
      end if
    else
      answer "Must use 5-digit CSI section number"
    end if
  end if
end mouseUp
```

D.3 CSI Sort Script

```
on mouseUp
  if the hilite of card button id 1 is false and ¬
  the hilite of card button id 2 is false and ¬
  the hilite of card button id 3 is false and ¬
  the hilite of card button id 4 is false and ¬
  the hilite of card button id 5 is false and ¬
  the hilite of card button id 6 is false and ¬
  the hilite of card button id 7 is false and ¬
  the hilite of card button id 8 is false and ¬
  the hilite of card button id 9 is false and ¬
  the hilite of card button id 11 is false and ¬
  the hilite of card button id 12 is false and ¬
  the hilite of card button id 13 is false and ¬
  the hilite of card button id 14 is false and ¬
  the hilite of card button id 15 is false and ¬
  the hilite of card button id 16 is false and ¬
  the hilite of card button id 17 is false
  then
    answer "No divisions have been selected"
  else
    lock screen
    unmark all cards
    go to stack "hyperspec"
    put the number of cards in this stack into tot
    unmark all cards
    go to card id 4213 in stack "bldgsys home"

    if the hilite of card button id 1 is true then
      go to stack "hyperspec"
      mark cards where background field "CSI" >= 01000 and ¬
      background field "CSI" < 02000
      put the number of marked cards into z
      go to card id 4213 in stack "bldgsys home"
      unlock screen
      put z into card field id 26
      lock screen
    else
      unlock screen
      put "0" into z
      lock screen
      put "" into card field id 26
    end if
    put z into x

    if the hilite of card button id 2 is true then
      go to stack "hyperspec"
```

```

mark cards where background field "CSI" >= 02000 and ¬
background field "CSI" < 03000
put the number of marked cards into z
go to card id 4213 in stack "bldgsys home"
unlock screen
put z - x into card field id 27
lock screen
put z into x
else
unlock screen
put "" into card field id 27
lock screen
end if

if the hilite of card button id 3 is true then
go to stack "hyperspec"
mark cards where background field "CSI" >= 03000 and ¬
background field "CSI" < 04000
put the number of marked cards into z
go to card id 4213 in stack "bldgsys home"
unlock screen
put z - x into card field id 28
lock screen
put z into x
else
unlock screen
put "" into card field id 28
lock screen
end if

if the hilite of card button id 4 is true then
go to stack "hyperspec"
mark cards where background field "CSI" >= 04000 and ¬
background field "CSI" < 05000
put the number of marked cards into z
go to card id 4213 in stack "bldgsys home"
unlock screen
put z - x into card field id 29
lock screen
put z into x
else
unlock screen
put "" into card field id 29
lock screen
end if

if the hilite of card button id 5 is true then
go to stack "hyperspec"

```

```

mark cards where background field "CSI" >= 05000 and ¬
background field "CSI" < 06000
put the number of marked cards into z
go to card id 4213 in stack "bldgsys home"
unlock screen
put z - x into card field id 30
lock screen
put z into x
else
unlock screen
put "" into card field id 30
lock screen
end if

if the hilite of card button id 6 is true then
go to stack "hyperspec"
mark cards where background field "CSI" >= 06000 and ¬
background field "CSI" < 07000
put the number of marked cards into z
go to card id 4213 in stack "bldgsys home"
unlock screen
put z - x into card field id 31
lock screen
put z into x
else
unlock screen
put "" into card field id 31
lock screen
end if

if the hilite of card button id 7 is true then
go to stack "hyperspec"
mark cards where background field "CSI" >= 07000 and ¬
background field "CSI" < 08000
put the number of marked cards into z
go to card id 4213 in stack "bldgsys home"
unlock screen
put z - x into card field id 32
lock screen
put z into x
else
unlock screen
put "" into card field id 32
lock screen
end if

if the hilite of card button id 8 is true then
go to stack "hyperspec"

```

```

mark cards where background field "CSI" >= 08000 and ¬
background field "CSI" < 09000
put the number of marked cards into z
go to card id 4213 in stack "bldgsys home"
unlock screen
put z - x into card field id 33
lock screen
put z into x
else
unlock screen
put "" into card field id 33
lock screen
end if

if the hilite of card button id 9 is true then
go to stack "hyperspec"
mark cards where background field "CSI" >= 09000 and ¬
background field "CSI" < 10000
put the number of marked cards into z
go to card id 4213 in stack "bldgsys home"
unlock screen
put z - x into card field id 35
lock screen
put z into x
else
unlock screen
put "" into card field id 35
lock screen
end if

if the hilite of card button id 11 is true then
go to stack "hyperspec"
mark cards where background field "CSI" >= 10000 and ¬
background field "CSI" < 11000
put the number of marked cards into z
go to card id 4213 in stack "bldgsys home"
unlock screen
put z - x into card field id 36
lock screen
put z into x
else
unlock screen
put "" into card field id 36
lock screen
end if

if the hilite of card button id 12 is true then
go to stack "hyperspec"

```

```

mark cards where background field "CSI" >= 11000 and ¬
background field "CSI" < 12000
put the number of marked cards into z
go to card id 4213 in stack "bldgsys home"
unlock screen
put z - x into card field id 37
lock screen
put z into x
else
unlock screen
put "" into card field id 37
lock screen
end if

if the hilite of card button id 13 is true then
go to stack "hyperspec"
mark cards where background field "CSI" >= 12000 and ¬
background field "CSI" < 13000
put the number of marked cards into z
go to card id 4213 in stack "bldgsys home"
unlock screen
put z - x into card field id 38
lock screen
put z into x
else
unlock screen
put "" into card field id 38
lock screen
end if

if the hilite of card button id 14 is true then
go to stack "hyperspec"
mark cards where background field "CSI" >= 13000 and ¬
background field "CSI" < 14000
put the number of marked cards into z
go to card id 4213 in stack "bldgsys home"
unlock screen
put z - x into card field id 39
lock screen
put z into x
else
unlock screen
put "" into card field id 39
lock screen
end if

if the hilite of card button id 15 is true then
go to stack "hyperspec"

```

```

mark cards where background field "CSI" >= 14000 and ¬
background field "CSI" < 15000
put the number of marked cards into z
go to card id 4213 in stack "bldgsys home"
unlock screen
put z - x into card field id 40
lock screen
put z into x
else
unlock screen
put "" into card field id 40
lock screen
end if

if the hilite of card button id 16 is true then
go to stack "hyperspec"
mark cards where background field "CSI" >= 15000 and ¬
background field "CSI" < 16000
put the number of marked cards into z
go to card id 4213 in stack "bldgsys home"
unlock screen
put z - x into card field id 41
lock screen
put z into x
else
unlock screen
put "" into card field id 41
lock screen
end if

if the hilite of card button id 17 is true then
go to stack "hyperspec"
mark cards where background field "CSI" >= 16000 and ¬
background field "CSI" < 17000
put the number of marked cards into z
go to card id 4213 in stack "bldgsys home"
unlock screen
put z - x into card field id 42
lock screen
put z into x
else
unlock screen
put "" into card field id 42
lock screen
end if

go to stack "hyperspec"
put the number of marked cards into marked

```



```
    go to card id 4213 in stack "bldgsys home"  
    unlock screen  
    put tot into card field id 45  
    put marked into card field id 46  
end if  
end mouseUp
```

D.4 Go To Cards Script

```
on mouseUp
  lock screen
  go to stack "hyperspec"
  if the number of marked cards > "0" then
    sort marked cards ascending numeric by background field "CSI"
    go to card id 4213 of stack "bldgsys home"
    go to the first marked card of stack "hyperspec"
    unlock screen
  else
    go to card id 4213 of stack "bldgsys home"
    unlock screen
    answer "No cards have been selected."
  end if
end mouseUp
```

D.5 Parts List Script

```
on mouseUp
  unmark all cards
  put 0 into markedt
  set lockMessages to true
  lock screen
  go to stack "hyperspec"
  sort cards by field "card name"
  sort stack ascending by background field "hide"
  unmark all cards
  put the number of cards in this stack into total
  go to card "list" of stack "bldgsys home"
  put total into card field id 28
  put "" into card field id 27

  if the hilite of card button id 26 is false and ¬
    the hilite of card button id 11 is false and ¬
    the hilite of card button id 22 is false and ¬
    the hilite of card button id 23 is false and ¬
    the hilite of card button id 24 is false and ¬
    the hilite of card button id 25 is false
  then
    unlock screen
    answer "No groups have been selected."
  else
    put 0 into s
    put 0 into t
    put 0 into u
    put 0 into v
    put 0 into w
    put 0 into x
    put 0 into a

    if the hilite of button id 26 is true
    then
      put "" into card field id 21
      go to stack "hyperspec"
      mark cards where background field "level" contains "subsystem"
      put the number of marked cards into re
      add re to a
      go to the first marked card
      repeat for re times
        add 1 to s
        get the short name of this card
        go to card "list" of stack "bldgsys home"
        put it into line s of card field id 21
      unlock screen
```

```

        lock screen
        go to recent card of stack "hyperspec"
        go to the next marked card
    end repeat
    unmark all cards
    go to card "list" of stack "bldgsys home"
else
    put "" into card field id 21
end if

if the hilite of button id 11 is true
then
    put "" into card field id 1
    go to stack "hyperspec"
    mark cards where background field "level" contains "level 1"
    put the number of marked cards into re
    add re to a
    go to the first marked card
    repeat for re times
        add 1 to t
        get the short name of this card
        go to card "list" of stack "bldgsys home"
        put it into line t of card field id 1
        unlock screen
        lock screen
        go to recent card of stack "hyperspec"
        go to the next marked card
    end repeat
    unmark all cards
    go to card "list" of stack "bldgsys home"
else
    put "" into card field id 1
end if

if the hilite of button id 22 is true
then
    put "" into card field id 17
    go to stack "hyperspec"
    mark cards where background field "level" contains "level 2"
    put the number of marked cards into re
    add re to a
    go to the first marked card
    repeat for re times
        add 1 to u
        get the short name of this card
        go to card "list" of stack "bldgsys home"
        put it into line u of card field id 17
        unlock screen

```

```

        lock screen
        go to recent card of stack "hyperspec"
        go to the next marked card
    end repeat
    unmark all cards
    go to card "list" of stack "bldgsys home"
else
    put "" into card field id 17
end if

if the hilite of button id 23 is true
then
    put "" into card field id 18
    go to stack "hyperspec"
    mark cards where background field "level" contains "level 3"
    put the number of marked cards into re
    add re to a
    go to the first marked card
    repeat for re times
        add 1 to v
        get the short name of this card
        go to card "list" of stack "bldgsys home"
        put it into line v of card field id 18
        unlock screen
        lock screen
        go to recent card of stack "hyperspec"
        go to the next marked card
    end repeat
    unmark all cards
    go to card "list" of stack "bldgsys home"
else
    put "" into card field id 18
end if

if the hilite of button id 24 is true
then
    put "" into card field id 19
    go to stack "hyperspec"
    mark cards where background field "level" contains "level 4"
    put the number of marked cards into re
    add re to a
    go to the first marked card
    repeat for re times
        add 1 to w
        get the short name of this card
        go to card "list" of stack "bldgsys home"
        put it into line w of card field id 19
        unlock screen

```

```

        lock screen
        go to recent card of stack "hyperspec"
        go to the next marked card
    end repeat
    unmark all cards
    go to card "list" of stack "bldgsys home"
else
    put "" into card field id 19
end if

if the hilite of button id 25 is true
then
    put "" into card field id 20
    go to stack "hyperspec"
    mark cards where background field "level" contains "element"
    put the number of marked cards into re
    add re to a
    go to the first marked card
    repeat for re times
        add 1 to x
        get the short name of this card
        go to card "list" of stack "bldgsys home"
        put it into line x of card field id 20
        unlock screen
        lock screen
        go to recent card of stack "hyperspec"
        go to the next marked card
    end repeat
    unmark all cards
    go to card "list" of stack "bldgsys home"
else
    put "" into card field id 20
end if

go to stack "hyperspec"
unmark all cards
go to card "list" of stack "bldgsys home"

if the hilite of card button id 26 is true
then
    go to stack "hyperspec"
    mark cards where background field "level" contains "subsystem"
    go to card "list" of stack "bldgsys home"
else
end if

if the hilite of card button id 11 is true
then

```

```

        go to stack "hyperspec"
        mark cards where background field "level" contains "level 1"
        go to card "list" of stack "bldgsys home"
    else
    end if

    if the hilite of card button id 22 is true
    then
        go to stack "hyperspec"
        mark cards where background field "level" contains "level 2"
        go to card "list" of stack "bldgsys home"
    else
    end if

    if the hilite of card button id 23 is true
    then
        go to stack "hyperspec"
        mark cards where background field "level" contains "level 3"
        go to card "list" of stack "bldgsys home"
    else
    end if

    if the hilite of card button id 24 is true
    then
        go to stack "hyperspec"
        mark cards where background field "level" contains "level 4"
        go to card "list" of stack "bldgsys home"
    else
    end if

    if the hilite of card button id 25 is true
    then
        go to stack "hyperspec"
        mark cards where background field "level" contains "element"
        go to card "list" of stack "bldgsys home"
    else
    end if

    put a into card field id 27
    unlock screen
end if
end mouseUp

```

D.6 Subsystem List Script

```
on mouseUp
  unmark all cards
  set lockMessages to true
  put "" into card field id 1
  put "" into card field id 17
  put "" into card field id 18
  put "" into card field id 19
  put "" into card field id 20

  lock screen
  go to stack "hyperspec"
  unmark all cards
  go to recent card of stack "bldgsys home"

  put 0 into a

  if the hilite of card button id 11 is false and ¬
  the hilite of card button id 22 is false and ¬
  the hilite of card button id 23 is false and ¬
  the hilite of card button id 24 is false and ¬
  the hilite of card button id 25 is false
  then
    unlock screen
    answer "No groups have been selected."
  else

    put item 1 of card field id 21 into sel

    if the hilite of card button id 11 is true
    then
      go to stack "hyperspec"
      mark cards where background field "level" contains "level 1"¬
      and the hilite of card button sel is true
      go to recent card of stack "bldgsys home"
    else
      end if

    if the hilite of card button id 22 is true
    then
      go to stack "hyperspec"
      mark cards where background field "level" contains "level 2"¬
      and the hilite of card button sel is true
      go to recent card of stack "bldgsys home"
    else
      end if

    if the hilite of card button id 23 is true
```



```

then
  go to stack "hyperspec"
  mark cards where background field "level" contains "level 3"→
  and the hilite of card button sel is true
  go to recent card of stack "bldgsys home"
else
end if

if the hilite of card button id 24 is true
then
  go to stack "hyperspec"
  mark cards where background field "level" contains "level 4"→
  and the hilite of card button sel is true
  go to recent card of stack "bldgsys home"
else
end if

if the hilite of card button id 25 is true
then
  go to stack "hyperspec"
  mark cards where background field "level" contains "element"→
  and the hilite of card button sel is true
  go to recent card of stack "bldgsys home"
else
end if

go to stack "hyperspec"
put the number of marked cards into a

put 1 into l1
put 1 into l2
put 1 into l3
put 1 into l4
put 1 into el

go to the first marked card
repeat a times

get the short name of this card

  if background field "level" contains "level 1"
  then
    go to card "subsystem list" of stack "bldgsys home"
    put it into line l1 of card field id 1
    unlock screen
    lock screen
    add 1 to l1
    go to recent card of stack "hyperspec"
  else

```

```

end if

if background field "level" contains "level 2"
then
  go to card "subsystem list" of stack "bldgsys home"
  put it into line 12 of card field id 17
  unlock screen
  lock screen
  add 1 to l2
  go to recent card of stack "hyperspec"
else
end if

if background field "level" contains "level 3"
then
  go to card "subsystem list" of stack "bldgsys home"
  put it into line 13 of card field id 18
  unlock screen
  lock screen
  add 1 to l3
  go to recent card of stack "hyperspec"
else
end if

if background field "level" contains "level 4"
then
  go to card "subsystem list" of stack "bldgsys home"
  put it into line 14 of card field id 19
  unlock screen
  lock screen
  add 1 to l4
  go to recent card of stack "hyperspec"
else
end if

if background field "level" contains "element"
then
  go to card "subsystem list" of stack "bldgsys home"
  put it into line e1 of card field id 20
  unlock screen
  lock screen
  add 1 to e1
  go to recent card of stack "hyperspec"
else
end if

go to the next marked card

end repeat

```

```
go to card "subsystem list" of stack "bldgsys home"

if the hilite of card button id 25 is true and el = 1
then
    put "nothing found" into line 10 of card field id 20
else
end if

if the hilite of card button id 24 is true and el = 1
then
    put "nothing found" into line 10 of card field id 19
else
end if

if the hilite of card button id 23 is true and el = 1
then
    put "nothing found" into line 10 of card field id 18
else
end if

if the hilite of card button id 22 is true and el = 1
then
    put "nothing found" into line 10 of card field id 17
else
end if

if the hilite of card button id 11 is true and el = 1
then
    put "nothing found" into line 10 of card field id 1
else
end if

end if

put a into card field id 27
unlock screen
end mouseUp
```

D.7 Standards List Script

```
on mouseUp
  unmark all cards
  set lockMessages to true
  lock screen
  go to stack "standardstack"
  sort cards by field "card name"
  unmark all cards
  go to card "standardslist" of stack "bldgsys home"
  put "" into card field id 27
  unlock screen
  put 0 into s
  put "" into card field id 20
  lock screen
  go to stack "standardstack"
  put the number of cards into re
  repeat for re times
    add 1 to s
    get the short name of this card
    go to card "standardslist" of stack "bldgsys home"
    put into line s of card field id 20
    unlock screen
    lock screen
    go to recent card of stack "standardstack"
    go to the next card
  end repeat
  go to card "standardslist" of stack "bldgsys home"
  put re into card field id 27
end mouseUp
```

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