IMPACT OF MEDIA ON SPATIAL COMMUNICATION

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Web Version

Chapter 1. The Challenge: Improve Collaboration and Communication

1.1 The Problem: The poor use of digital media in AEC industry

Many of the artifacts we use today, whether the structures we inhabit, the vehicles we travel in, or the computers we work on, are increasingly designed by specialists working from remote locations who interact by using a collaborative design processes. Central to those processes is effective, timely communication media, whose technology (and the affordances[1] it provides) does not incur significant effort that may overburden the collaborators. Computer-aided design (CAD) promised to be this collaboration medium at its introduction. The wide acceptance and proliferation of 2D CAD[2] has increased the speed at which information is created and communicated. However, realization of the full potential of CAD in the AEC industry has been limited by the conventional methods, procedures and practices used by each of the collaborating disciplines, which were established when paper was the primary medium of communication. CAD instead has seen its primary role as a drafting tool used in the construction and management of documents composed of lines and geometric shapes.

The AEC industry has seen a significant increase in the number of specialists needed to design even simple facilities, and a commensurate increase in the volume of information exchanged. Herbert Simon estimated that

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1 The term affordances, coined by psychologist James Gibson, describes a potential for action, the perceived capacity of an object to enable the assertive will of the actor [Gibson 1977].

once a profession reaches the point where it takes 10 years to master, it tends to break into specializations [H.A. Simon, 1969]. In the late 1980's there were about twenty-five different fields of specialization [R. Gutman, 1988, p.34]. Today it is not unheard of to have over one hundred specialists working on a major project [D. Cuff, 1991]. Over time, each discipline has developed its own language (symbols and codes) for communicating. The number and variety of codes used by the different disciplines are such that the reader must rely on a code sheet to fully understand the symbols involved. This has put a greater strain on the communication systems currently supporting this collaborative process. In addition, many of today's large buildings are becoming more complex. A university building at the turn of the century would commonly contain no more than 5 to 10% of its cost in mechanical and electrical systems. "Today those systems would comprise over half the cost of a new science building. If anything the design and coordination efforts for those systems has escalated even more than the construction cost" [R. Schulz, 1999]. As such, selecting the appropriate medium for the task will have a significant affect on the costs of the project.

Past communication systems using drawings on paper are no longer adequate to support the growing complexity of designing such structures: they generate waste and errors which, in the past, were simply 'rolled in' to the cost of doing business. As the complexity of the artifacts grows, so do waste and errors, reaching a level that can no longer be ignored.

The paper based communication system we have been using for the past

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2 Employing a CAD system to create two dimensional lines and shapes.

500 years has certain inherent limitations:

- incomplete information
- delayed information
- inaccurate information
- difficult to modify the information
- inability to effectively represent certain types of information

These shortcomings were accepted because paper was the only effective system of communication available to designers; creating a two-dimensional shorthand intended to compensate for the difficulty of representing three-dimensional objects [R. Aish, 1992, p.99]. The advent of computer-based representation and communication has changed that, making available tools and methods that have greater efficacy for communication than paper. However, even though the digital media of CAD has become commonplace, the implementation of this tool has been clerical[3] in nature, increasing the speed of communication, but not utility. Increasing the speed at which 2D lines on paper are generated and communicated among the AEC specialists misses the opportunities that CAD offers in terms of greater accuracy, flexibility and completeness of information exchange within the collaborative process.

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3 I use the term 'clerical' here to denote the rudimentary application of CAD to the effort of communication within the AEC industry.

1.2 The Symptom: Misuse of digital media in the architectural design process

The focus of implementing CAD by the AEC industry has been improving the creation and sharing of 2D documents rather than the greater objective of improving communication within the collaborative process. In effect, CAD tools have emulated paper-based representation and communication methods, including their inherent shortcomings. For example, paper is limited as far as how many marks can be made on its surface before it becomes too difficult to read. When this level is reached, another piece of paper must be added. At some point, the large number of collated papers begins to impede communication. Thus it can be said that there is a limit on how many elements or how much data paper can contain before its effectiveness begins to decline. In part, this limitation defines the affordances of paper as a communication medium. To compensate for this limitation, AEC professionals developed sets of symbols and structures that increased paper's capacity to encode more information. Although these symbols and structures have been successful in extending these affordances of paper, this solution has created a greater dependence on the shared understanding of these symbols by the communicating professionals. Furthermore, although an agreed upon set of symbols (code) allows more information to be placed on a page, the author of the document must still choose what information to communicate in the document and what to leave out. Incorrect choices can obviously lead to errors. Although CAD does not have a limitation on how much information can be embedded, the current 2D implantation of CAD and continuing reliance on these codes and symbols maintains the reliance on shared knowledge.

1.3 Solution: Changing the way we think about and use new media

Communication is important to effective and efficient collaboration. All forms of communication require some medium that can support the encoding, transmission and decoding of the communicated messages. A wide range of media is available to support communication. Each medium has its own advantages and disadvantages, depending upon the requirements of the communication. The disadvantages or limitations of any given medium can, in fact, force the sender to compromise the completeness and accessibility of the message. Direct comparison of different media is not always feasible. However, it is possible to examine the actual effort people require within each medium to 'reason about, communicate, document and preserve knowledge' [E. Tuft, 1990, p.33]. Some forms of media are better suited than others for exchanging data and information within the ever-accelerating time frames of the AEC industry. By analyzing the

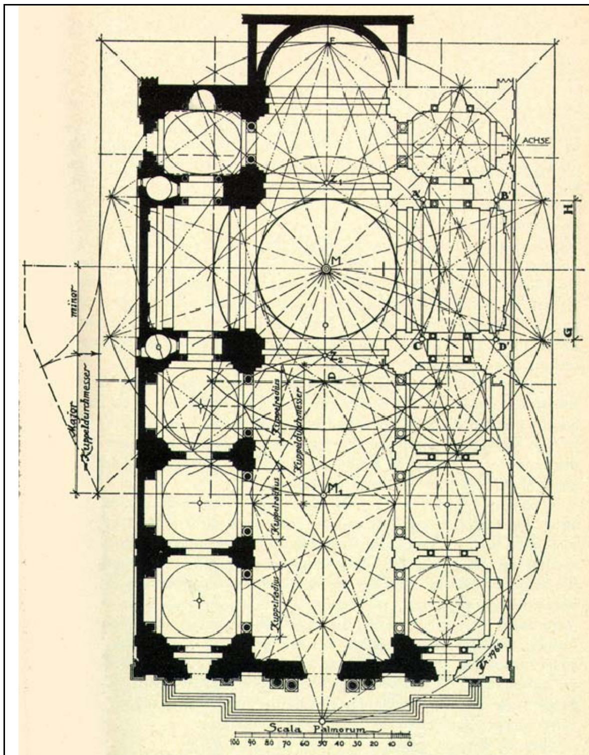

Figure 1: Example of too much graphic data causing the actual information to be difficult to discern.

various types of media available, we can improve our ability to understand, select and use existing media and more effectively explore the possibilities of future media to support collaboration.

In 1963, Ivan Sutherland used a TX-2 computer at MIT's Lincoln Laboratory to produce a project called SKETCHPAD, which is considered the first step in the CAD industry [J. Lansdown, 1985, p.61]. In the 1970s and 1980s many research efforts were initiated that further defined the promise of CAD including CEDER (computer-aided Environmental Design Analysis & Realization) [S. Fenves et al., 1994, p.23] and IBDE (Integrated Building Design Environment) [N. Cross, 1977, p.25]. Lack of acceptance of these tools in the typical architectural office was understandable due to expensive hardware and software, limited computing power and an interface that requires a technician to exploit its full potential [J. Lansdown, 1985, p.61]. The 1980s saw CAD develop in two directions: large workstations that typically had dedicated hardware and software vs. personal desktop systems with general operating systems and applications [A. Andia, 2001, pp.678-679]. The mainframe system was sophisticated, even by today's standards, providing 3D solid object support, collaboration over an intranet and dynamic display

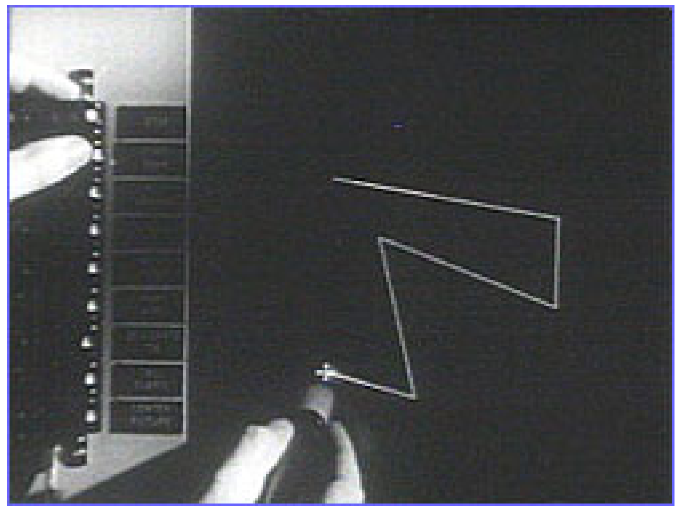

Figure 2: Ivan Sutherland demonstrates Sketchpad

capability. The desktop was primarily used in clerical tasks; drawing lines, photo editing, maintaining records and performing simple spreadsheet calculations. The 1990s saw desktop systems explode in capability, power and usability while costing a fraction of previous prices. Yet, these systems still performed, although with a bit more sophistication, the same clerical tasks. We have now entered the 21st century, and although our desktop machines dwarf workstations of the past in capability and are usually connected through the Internet, we still see the typical use of CAD as a drafting tool. Although there are systems today that provide significant improvements in information representation and exchange, they have not been adopted by large segments of the AEC industry. This can probably be attributed to the high level of effort required to use these systems. The high level of effort is not due simply to the tools being too complex and cumbersome, although that is still a recognized problem [C. Eastman, 2001, p.4], but primarily to the reluctance of the industry to accept radical change to its current practices. We are "essentially accepting the ultimate pragmatic response which is to do nothing and accept the existing architectural drawing conventions as the communication medium" [R. Aish, 1992, p.99]. Many of our customs, laws and even how we value ourselves, also known as "our image of practice" [K. Boulding, 1956], are still tied to protocols and procedures that are based on the paper medium. Despite this situation, change is coming, albeit slowly. Digital media offer many advantages, and although it is not practical to provide a complete list of attributes this new medium can support, there are a few central affordances that should be mentioned:

- Explicit representation of the information
- A display that can support interaction and modification of intelligent documents
- A standard information exchange format to ease the sharing of information
- Support of real-time and asynchronous communication
- Low effort of procurement and operation of the system

Many CAD tools are beginning to incorporate the attributes listed above, and the industry is hard at work trying to establish a standard of practice to support these capabilities. Unfortunately, just creating a product that can perform the functions listed above is not enough. A profound change in how we think about the use of CAD must occur. To support this change in thinking, we must not only make improvements in what is offered to the professional community, but also create tools to demonstrate the advantages of such systems and the importance of collaboration.

In this dissertation, I lay out a different way of thinking about media and its use in the AEC industry. Within this way of thinking we can compare past, present and future communication media and what they can offer. To illustrate this, I have also created a program that allows students to experience thinking and practicing in this new mode of communication as well as experience some aspects of the effects of improved collaborative communication.

Chapter 2. Representation: The Affect of Affordances and Effort on Choosing the Correct Medium for the Message

2.1 Dependencies and Variables of a Communication System: Affordances, Abstraction, Quantity

The effectiveness or utility of most communication systems is measured by their ability to support encoding, transmitting and decoding information. This ability depends, in part, on the interaction of three interdependent capabilities (1) the affordances of the medium being used, (2) the abstraction level and structure which depends on the skills and experience of the participants using the medium, (3) the quantity of data which can be communicated effectively which is derived from the first two capabilities.

The goal of communication is to allow the sender to provide the receiver with information. In order for this to happen, the sender's message must embody the information (and meaning) that will satisfy the sender's understanding of the receiver's requirements. Since the AEC industry is primarily concerned with the built environment, the communications (and the messages contained therein) tend to refer to spatial entities and their assemblage. This dissertation is therefore focused on the communication of spatial information and its specifications.

2.1.1 Affordances of a Medium

Most media can be understood using the following construct: The act of communication, in simple terms, requires that information is exchanged between a sender and a receiver via some chosen medium. Information is encoded into a message through the composition of symbols (elements and data) that the chosen medium can support. Information is received by the interpretation of the message's symbols from the display by the receiver.

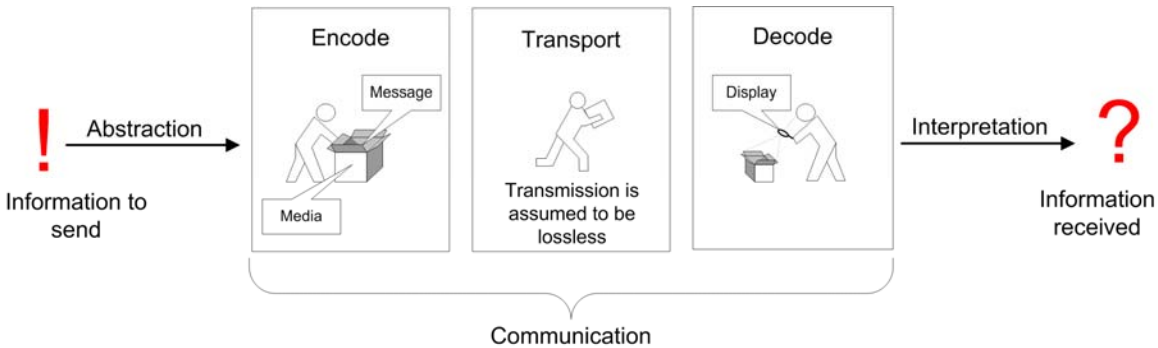

Figure 3: Media within the Act of Communication.

Although I refer to paper as a medium of communication, it should be understood that paper by and of itself is not enough. The marks made on paper and the devices used to make those marks are part of a system for communicating information using the medium of paper[4]. In the same respect, a computer is not a medium, but the system of hardware and software together is a medium. Every medium carries with it certain constraints on the ways in which it can represent a message. For example, information on paper cannot interact with the user; air (the typical medium used for transmitting sound) has a short life span; a computer requires electricity; and writings made in sand are very difficult to transport. "Computers represent a new medium, or should we say several new

4 I will not delve into an abstract discussion about the hand being part of the system, or using a muddy shoe to create a mark as a writing system. Instead I am only concerned with the purposeful intention to create a substantial message that imparts information to the receiver.

media" [J. Hare, 1992, p. 68]. A computer is a unique medium because the way in which it is constructed and programmed will have a significant influence on the system's ability to represent the message.

2.1.2 The Three Elements of Communication: Encode, Transmit, Decode

A common framework used by the major schools of thought on communication separates the communication process into three essential components (1) the encoding of the information, (2) the transmission of the information through a channel and (3) the decoding of the information [C. Shannon, 1948, pp. 379-380].

In the most basic example, a written communication uses paper as its medium. The encoding of information involves making a series of scribed symbols (letters and numbers) that best represent a message by using a preset code e.g. the (English language). The transmission is the transportation (by hand) of the encoded message from the sender to the receiver. The decoding is the interpretation (reading) of the displayed symbols and their relative position into ideas that can be understood by the receiver. In the communication process, there must be an agreement on both the sender's and the receiver's part as to just what the symbols (data) used in the communication represent. This agreement is a shared knowledge between the communicators.[5]

Similar rules apply to information technology systems that we use for

5 This dissertation does not explore the issues related to a shared knowledge that is inaccurate. It assumes that send and receiver share the same understanding of the symbols used.

communication. They also rely on mutually accepted and relatively standard definitions and procedures to encode, transport and decode information. It should be noted that in this dissertation, manipulating preexisting information, as well as integrating information from other sources, is considered part of the encoding process.

Encoding

In order to communicate, information from the sender must be encoded into a medium which means that new data is either created or existing data is manipulated to represent the message. Coding information is a form of abstraction, one that necessarily abbreviates or summarizes information to a level that facilitates actual transmission over an established medium.

Abstraction can be viewed as the purposeful exclusion or aggregation of certain details into another (typically simpler) representation [E. Steinfeld, & Y. Kalay, 1990]. As such, some information must be reconstructed from the abstraction; the greater the level of abstraction, the greater the potential for error during reconstruction. To mitigate this, extra effort must be employed to check the accuracy of an interpretation or correct errors that may result from incorrect interpretation. As such, the use of abstraction creates a dependency on shared knowledge.

As participants work together more often, they can develop a greater shared knowledge and therefore more sophisticated abstraction levels and structures can be employed. There is always a tradeoff when selecting the level of abstraction for a given set of information. In general, higher levels of abstraction result in smaller quantities of data in the message but depend on the shared knowledge of the receiver to decode the message incurring greater risk of error, whereas lower levels of abstraction produce larger quantities of data in the message but can be more difficult to manage depending on the medium employed.

Transmitting

Once information is encoded into a medium, it can be transmitted through physical movement[6], observation or broadcasting. Typically, the transportation of the message should not compromise the integrity of the message. Of course, there are examples of distortion introduced within the transmission process by the form of transportation, but the technical implications of such exceptions are not considered in this dissertation. We will assume that transmission is lossless.

Decoding

The last step in the communication process is decoding. Decoding requires that the message can be displayed to the receiver. In the AEC industry, this is typically accomplished visually. The receiver of the message must be able to interpret, or decode, the message from the symbols (data) presented.

A display is the means by which a medium provides visual access to the data[7]. A static display system (like paper) can only display information one way, the way it was encoded within the medium. A dynamic display system (like a computer) will be able to display the same information in a variety of ways. For example, consider this message; "the setback for this structure is five feet." The message is written in

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6 Electric transportation can be considered a special manifestation of physical movement.

7 There are many media that mix interfaces; sight, sound, touch, temperature, etc.

English. However, the manner in which it was encoded into the medium will present a problem during decoding. If the viewer received the message on paper in an extremely small font, it is highly unlikely (if not impossible) that the message will be decoded unless some form of magnification is available.

Decoding also requires that the receiver has the shared knowledge to understand the message. For example: “la battuta d'arresto per questa struttura è cinque piedi.” In this case the encoder is using the Italian language for this message. Unless the receiver understands Italian, the message cannot be decoded without the assistance of additional tools. Therefore, while the information was coded into the medium in the correct manner, the sender chose a code which was incompatible with the abilities of an English-speaking receiver.

The previous example illustrates the dependency on shared knowledge for communication. Although it is not in the scope of this dissertation to explore the issues involved with differing understanding of a symbol, it should be noted that the confidence of this common understanding maintains a large influence over the level of abstraction used in a communication. For example, if I believe there exists a common understanding of the layout to the streets of Berkeley, I may send a message containing only the address to my office to the receiver. If, however, I feel that this understanding may not be complete, or there is a chance that our understanding may not be the same, I will send a more explicit communication, replete with maps and instructions. As such, the message I have created incurs more effort then what would have been required to send just an address.

2.1.3 Display: The Four Modalities of Media Interaction for Decoding

Many media can be employed for communication in a collaborative environment. One useful way to compare them is to look at their capabilities and limitations (affordances). The medium chosen will influence how information is encoded, transmitted and decoded. Since the common way we interact with a medium is through a display, the various types of media are divided into four categories composed of two variables: the medium's ability to embed and respond to the sender's instructions, which can be passive or active; and the medium's ability to respond to the receiver's interactions, which can be static or dynamic.

The terms that I am using here are from the view of the receiver, since it is the receiver that will engage the display. Although the term 'interactive' may be a better descriptor for the capability of the display, the term 'dynamic' was chosen instead because of its common use in computing to describe an element or an object that can respond to user input in a variety of ways. 'Active' tends to connote a more general interpretation of movement or activity.

Before exploring the modalities of display further, an example may be helpful. A person using computer visits a website. The display functionality of this website can be said to have one of four possible display modalities: The webpage can or cannot change its display (passive or active) and the viewer can or cannot change the display of the webpage (static or dynamic). Therefore, four possible combinations exist.

1) Passive/Static: A typical deployment of a webpage is with the use of

HTML[8]. The viewer cannot change the display nor can the display change itself. As such, we can say the webpage embodies a passive/static modality.

2) Passive/Dynamic: In this possibility, the webpage could be considered using DHTML (Dynamic - HTML). Buttons, sliders and other control widgets are available to the user to interact with and thus change the page's display[9]. In this case the manipulation of the widgets by the viewer connotes a dynamic interaction with the medium and thus the display. The page itself, however, does not determine when or how the viewer manipulates the display nor can it autonomously activate a widget. This is an example of a passive/dynamic modality.

3) Active/Static: Many web pages have animations or videos that load and play automatically as soon as the page is loaded. In this case, the sender of the message (the web programmer) controls how the display changes, making the display active. However, the viewer has no control over these changes, and as such is a static observer of the events unfolding. We can consider this example an active/static display modality.

4) Active/Dynamic: There are some web sites that load Flash or Java applets that not only support prescript actions, like animations, but also allow for user interaction. In this case the webpage can both actively change its display through prescribed instructions and dynamically respond to user interaction. This example would be considered active/dynamic.

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8 Hypertext Markup Language.

9 In this example, I am not considering timed JavaScript events or similar implementations.

The most common form of display is passive/static. Passive describes the information's inability to be modified within the display and static describes the viewer's inability to modify the display of the information. In a typical written communication, marks on paper are static and, as such, cannot be modified by the author or the viewer without new marks being added or old marks being partially or fully erased. This limitation is not always a deficit to communication. Final legal documents require just the affordances that passive/static offers. Milestone documents also tend to be printed. One of the reasons for this is that milestone prints create a landmark of the design at a particular stage thus requiring the display to be passive/static. It is not uncommon for a design firm to send both digital documents and printed documents at the same time.

The second most common form of display is passive/dynamic. The dynamic aspect of the passive/dynamic display allows the viewer to manipulate how the information is displayed without corrupting the original message. The best example of a dynamic display is a computer. Information contained within the computer is not directly dependent upon how it is displayed thus allowing the viewer to customize the display to aid in the decoding process. Another example of this is a physical model that can perform functions or be manipulated (e.g. doors that operate, lights that function, or floors that can be separated to allow views into occluded spaces).

Active/static is the least common of the four display methods used within the AEC industry although it is highly effective for some situations; client presentations for example. The active component here refers to the way information is displayed to the viewer. Film and video are good examples of this. Although the display is active, the user is unable to manipulate the display in a meaningful way and is forced to be a voyeur of the message as it unfolds over time[10]. Mechanical models that only operate autonomously are also considered active/static.

The most flexible modality for displaying a message is active/dynamic. Although it is becoming more popular, this method is not commonly used because typically the effort required to acquire, master and employ the tools is significantly higher then with tools that offer other display modalities. As with the passive/dynamic methods, the manner by which information is displayed is based on the active interaction of the viewer. These interactions can also generate new information to satisfy viewer needs that the author may not have anticipated. For example, the viewer may select a wall, causing a display to appear with information about the wall. Or the viewer may move an element in the medium causing a message to be communicated indicating the consequences of that move; whether this will cause an obstruction or violate structural integrity for example. Figure 4 shows an example of the placement of various media within the modality matrix just described.

10 In the spirit of this dissertation, I do not consider play, fast-forward and rewind sufficient to qualify as viewer interaction.

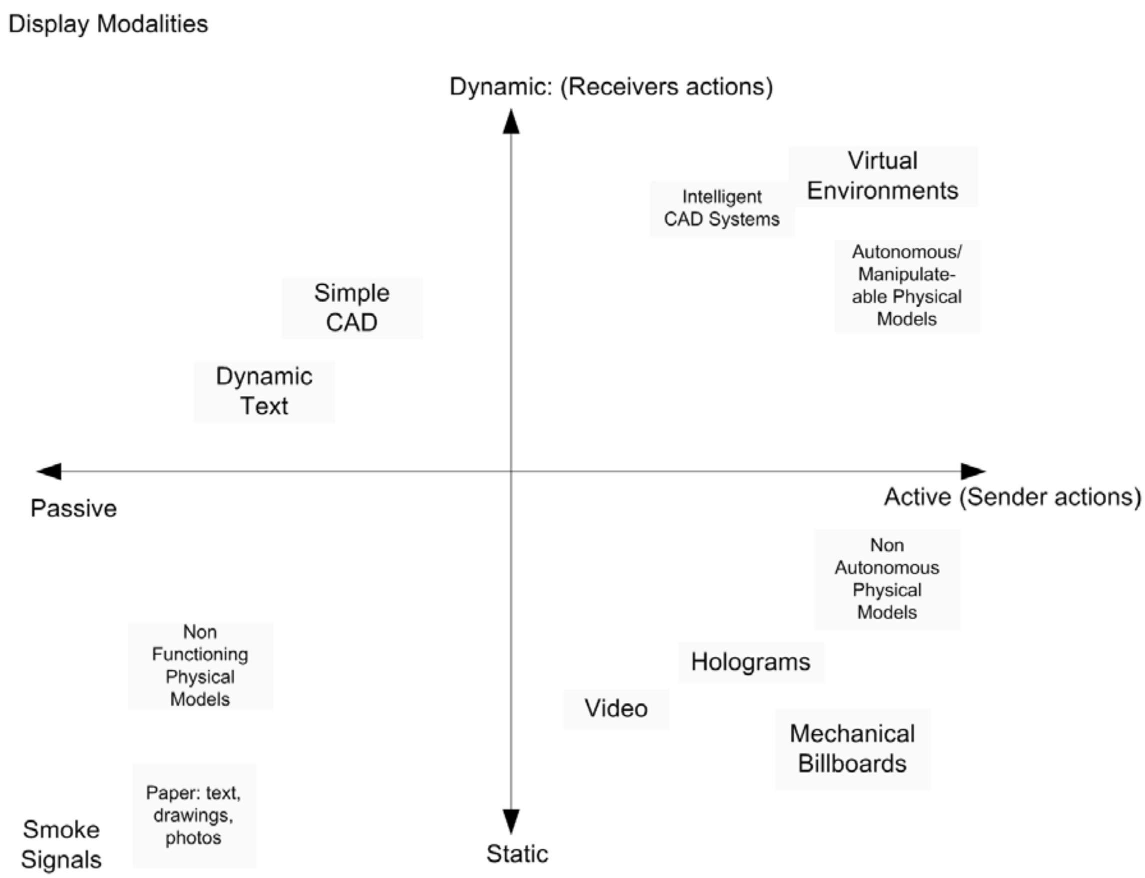

Figure 4: Examples of various media used for spatial communication and where they fit within the display modality matrix

2.2 Evaluating the Value of Communication

2.2.1 Value, Utility, Effort, Quantity

For the purposes of this dissertation, the value of a specific communication can be expressed as the difference between a communication's utility and the effort required to encode, transmit, and decode information with a given medium.

The utility of a particular message is a measure of how well it meets the informational needs of the communicating parties (both sender and receiver) in terms of their ability to reason about, communicate, document, and preserve intended knowledge within the specific communication. Superfluous data that are not needed by the receiver, or missing information that causes the receiver to ask for more information or for clarification, are considered undesirable and thus require extra effort to mitigate.

Effort is the amount of energy required to encode, transmit and decode a message within a given medium. This can include the effort to acquire and become proficient with the tools of the medium used.

Quantity is the actual number of elements or data embedded in a message.

2.2.2 The Effect of Quantity on a Medium's Resistance

When information is encoded into a medium, a certain amount of effort is required to create or manipulate elements of the medium to represent the message. As the quantity of elements (data) increases, so does the effort required to encode and decode it[11]. The malleability[12], or resistance to change, of the data used in the medium further influences effort. For example, the amount of effort required to create a simple one page drawing on paper is most likely the same, if not less than, creating that same drawing on a CAD system [personal

11 This ratio of increased quantity of data to increased effort is not always linear.

12 The ease of changing (adding, subtracting, modifying) information on a particular medium.

interviews, Baunsgard 2003, Black 2002, Meyer 2003].

However, when the amount of information to be created and edited increases, the amount of effort required using the CAD system will increase at a slower rate than the amount required using paper. This is in large part due to CAD's ability to selectively and easily access, modify and display data. The differences between paper and CAD as media also illustrate differences in the resistance of a medium to change as the quantity of data changes. This simple relationship between effort and quantity for a given utility is displayed in Figure 5.

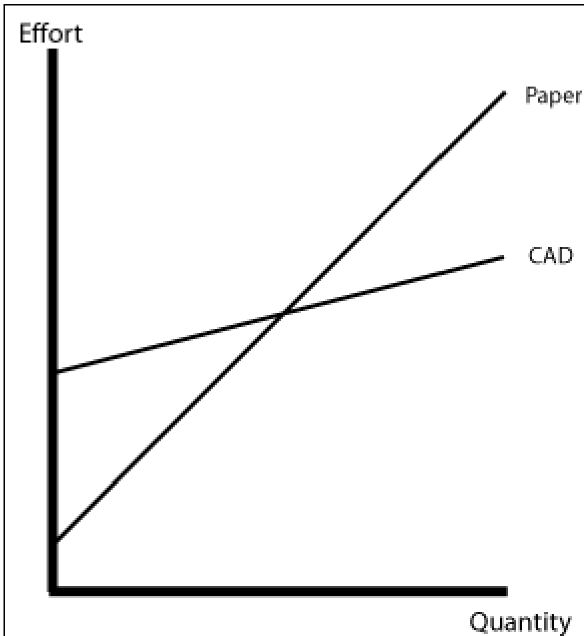

Figure 5: Effort vs. Quantity in respect to Utility.

Effort is also influenced by the resistance offered by a particular media during decoding. For example, reading information from a set of large sheets (36" x 42'' is typical) of paper drawings is easier then from a 17-21" (typical size) computer monitor. This is because more information can be displayed at once on a large sheet of paper then on a screen. Exploring that sheet of paper is also easier given; the ability to inspect different parts of a sheet of paper by shifting one's focus to different areas, move one's eyes closer to the sheet to see small detail, and pulling back for an overall view. The effort required to perform these same maneuvers on a screen requires changing what is displayed on the screen, showing some information while obscuring other, thus sacrificing continuity. So it might be said that the computer monitor incurs some level of resistance when displaying information. However, when the quantity of information is so large that it must span across multiple sheets of paper, then effort must be spent to cognitively resolve the different representation on different sheets. Here again effort is influenced by quantity.

The affordances of easy manipulation of information inclines people to favor computing for editing and integrating large information sets; paper's affordances for large display and flexible physical properties tends to be favored when presenting or marking up information. The fact that both media are still in use demonstrates a lack of capabilities of our current digital tools as well as how we use them. A tool that could perhaps employ the affordances of both paper and the computer display would be digital paper[13] (Figure 6). Such a medium would support the positive aspects of paper; a large display area, direct marking on the medium, and the physical properties of paper. It would also embody a dynamic display, thus inheriting many of affordances offered by the computer without incurring the extra effort demanded by both of the respective mediums.

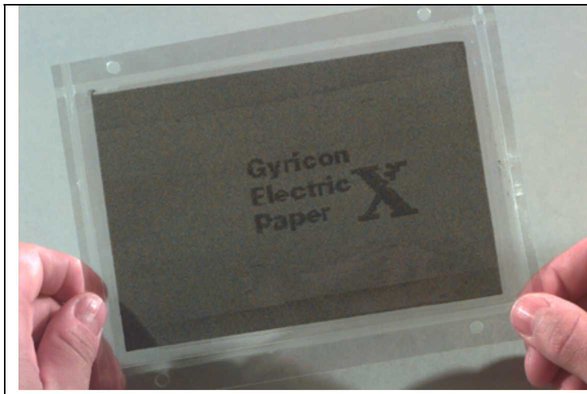

Figure 6: Digital Paper from The Palo Alto Research Center.

2.3 Choosing a Medium

Choosing the correct medium is not always an easy task. This is especially true when there is an increase in the number of variables which impact both the quantity of data and the ease of encoding and decoding the data. Typically, custom prevails over reason. Custom is the habitual reliance on previous practice. However, it is often useful to periodically reexamine the value of doing things the customary way. Typically, this entails a recalculation of the cost of changing media and the potential savings achieved through improved processes.

For any communication task, a medium must be selected to store and carry the message. Custom not withstanding, the medium chosen should be the one that can provide the highest utility at the lowest effort. To understand which medium can provide the maximum return on effort, one must take into account the quantity of data required by the communication. This, in turn, is influenced by the level of abstraction, and the affordances of the medium in question. For example, if the various participants have a high level of shared knowledge, then the messages exchanged will most likely be highly abstract. The primary medium employed will not require a system that embodies the affordances of communicating detailed instructions and large data sets, thus less expensive systems can be used.

However, if the participants have a low level of shared knowledge, they may

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13 http://www2.parc.com/dhl/projects/gyricon/

require a medium that is very flexible and can support detailed communications that typically require a large quantity of data. Although media that support this higher quantity and complexity tend to be expensive and difficult to use, they often compensate by allowing for more efficient communication. Finding that balance between the utility and effort of the medium is the objective in medium selection. Some examples may be instructive.

A university building was undergoing an emergency seismic retrofit, necessitating the relocation of all the classroom facilities within the period of a semester. Because of this time constraint, interim buildings had to be designed and constructed within that extremely compressed schedule. Because of the 'fast track' nature of the project, the documentation was necessarily highly abstract. The designers understood from the outset that this level of abstraction would create questions from the contractors, but it was understood that more information would be provided as the project progressed. In this case, the costs of errors resulting from insufficient information were less than the gains generated by accelerating the project. The methods of communication chosen, a combination of CAD, paper, and faxes; allowed fluid response to the rapid changes anticipated.

As a counter-example, we will consider the Guggenheim Museum in Bilbao, Spain. Many details had to be designed before construction could begin due to the complexity and exacting tolerances of the design. The cost of correcting an error which resulted from misinterpretation of a communication would have been far greater then what could have been gained by starting the project early. Here, the level of abstraction was very low since the communication contained detailed instructions for component construction by a special milling machine. Therefore, the investment in more expensive yet more capable tools, and the training to use them, was justified.

As a third example; a sender wishes to communicate information for constructing a shed. If the receiver has constructed many of these sheds before, then the sender can abstract the message to a high level thus sending a small amount of information. In this example a few sheets of paper will be sufficient. However, if the receiver does not have experience building sheds, then the sender must create a more explicit message. As such, more effort is required to generate the information and consequently more effort is required on the receiver to manage and explore the contents of the message to realize the required utility.

Chapter 3. Communication of Spatial Entities; Past influence on Current Practice

3.1 Communication at the beginning of the profession

The practices used for capturing, communicating, and coordinating the work of AEC specialists involved in the design of buildings have not changed significantly since orthographic drawings were used 500 years ago during the Renaissance. In fact, we know through Vitruvius that the use of plan, elevation and section were in use during the Roman Age [Vitruvius, 1.2.2] In the Middle Ages, all the knowledge needed to design and lead the construction of a building was contained within the master builder's experience and that master builder was on site overseeing the entire project.

The Renaissance brought a change in how buildings were designed and how construction was managed. The desire to return to the symmetry, proportion and regularity of the classic age meant that designs needed precision, and for that, everything had to be planned. A complete, detailed set of documents (plans, sections, and elevations) had to be created, which required architects to also become draftsmen. One of the first to recognize the communicative role of

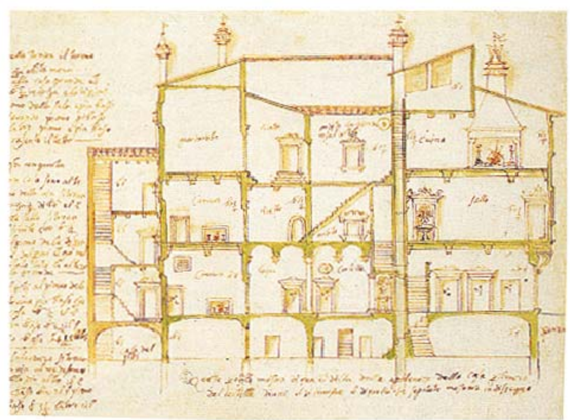

Figure 7: The longitudinal section. A new kind of representation used in the Renaissance [B. Jestaz, 1995, p.112].

drawings was Raphael, who wrote a letter to Pope Leo X in 1519 in which he explained the need to have drawings include both plans and sections drawn to the same scale. This way they could be placed one above the other, to minimize errors related to the measurements and placement of building components [B. Jestaz, 1995 p.138].

3.1.1 Perspective

In addition to scale drawings, another tool that allowed architects to be more confident in their communications, especially with the client, was the rediscovery of perspective rendering; exemplified by Alberti's Della Pittura of 1436 [J. Lansdown, 1992, p.61]. So compelling was this new understanding of perspective, that Bernini created a space in St. Peter's Square at the Vatican in Rome (known as Bernini's Columns) which employed various elements of perspective, including a focal point, counter-perspective effects, and accelerated perspective effects.

3.1.2 Physical models

The creation of two-dimensional drawings did not eliminate the need for physical models. The physical model, was the only means by which patrons (who were rarely architects or masons) could properly understand what was to be constructed. A model of St. Peters created by Antonio da Sangallo the Younger was so large and detailed that at a scale of 1:30 it took seven years to complete at a cost equivalent to that of a small country church [A. Frommel, 1994, p.40]. Nonetheless, the use of the physical model was so important that one of the first fields of specialization for architects was that of model builder. Many carpenters who specialized in building architectural models during the 15th century, like Antonio Manetti Ciaccheri, later became architects themselves.

3.1.3 Skills of an architect

Some of the most prominent Renaissance architects (e.g. Brunelleschi and Michelozzo) were goldsmiths. Since gold was such a precious commodity, they were required to do thorough planning and create drawings before any object was created. The need to represent 3D entities onto paper required drawing and abstraction skills that were perfect for this new vocation of master architect. In time, painters and sculptors took over, moving the field even farther away from practical applied skills and closer to drawing and theory. This is when the first pure architects appeared [B. Jestaz, 1995, p.119].

Alberti was the first major architect to rely completely upon craftsmen at the site. Because the documents he created to direct the construction process were the primary source of information for the builders, he needed to have a very high level of drafting skill in order to abstract three-dimensional entities to two-dimensional lines and shades on parchment. Relying purely on theory and his drawing skills, Alberti, who was an artist and nobleman, directed the construction process from afar. Architecture was being transformed, from a sole reliance on the personal knowledge and experience of master builders, to an art and science directed by an architect through the medium of paper.

3.2 Past communication, present demands

The advent of scale drawing, standard symbols and perspective rendering helped the discipline of architecture grow and evolve during the Renaissance. This was a major turning point in communication tools, techniques and protocols.

The form of spatial communication that was pioneered during the Renaissance provided the basis for what is used today in the construction industry. The design team creates a set of drawings that are sent to craftsmen at the construction site. Although modern, sophisticated structures require far more engineering expertise and many more collaborators, the medium we use to communicate this information has not changed significantly; abstracted two-dimensional drawings on paper is still the standard.

3.2.1 Synchrony

In collaborative design, it is quite common to have one designer's input affect the design of another. However, if the partnering designers are unaware of this, they will continue to develop designs that invariably must be changed. To minimize this effect, the originator of changed information must keep the other designers updated with the design revisions that affect them. A problem with this 'push' approach to design revisions is the possibility that not every participant who should be informed of the change is informed. Frequently this is because the originator of the changed information may not realize which participants will be affected. As such, some design changes are only discovered during more global coordination meetings.

This lag of updated information compounds the problem of synchrony. The ability to integrate information quickly and make it available to all collaborators is an important element, especially at the beginning of the collaborative process. Obviously it is not only designers who need access to timely information during the design phase. Clients, officials, and community groups could also benefit from this access by voicing concerns regarding a design early in the process instead of near the end, where changes can prove to be much more difficult and costly.

Although there are services that provide up-to-the-minute access to two-dimensional documents, this is only a partial solution. In many cases, the collaborators are subject to 'data overload' because the amount of information is simply increased, not easier to access. Designers need more pertinent information, not just more information.

3.3 Dynamic tools, static methods

Paper has been the primary medium for communication in the AEC industry for a long time. This medium has not only been integrated into current work practice, but, in fact, it defined these practices. Many of the laws, customs and tools still in place were created around the affordances of paper, thus making the transition to modern media more difficult. According to Sellen and Harper, there are three main reasons that people continue to rely on paper despite the burgeoning of digital devices populating today's modern office:

- The co-evolution of paper and work practices
- The inadequacy of digital alternatives
- The affordances of paper

The physical properties of paper (it is being thin, light, porous, opaque, flexible, and so on) afford many different human actions, such as grasping, carrying, manipulating, folding, and in combination with a marking tool, inscription [A. Sellen, & R. Harper, 2001, p.17]. Further, marks are (more or less) fixed with respect to the medium. On the other hand, these properties also mean that paper lacks certain affordances. Paper does not afford the display of dynamic information nor does if afford automatic updating or easy modification of its contents [A. Sellen, & R. Harper, 2001, p.18]. Although each of these reasons present a substantial barrier and opportunity to greater acceptance and implantation of modern media, by understanding these reasons we can better design and adapt to the possibilities modern media can offer.

Chapter 4. The Struggle In Moving To New Media

Even though today's CAD systems are capable of containing far more information than paper, many designers still apply the paradigm of paper communication to CAD. This can be attributed to our inherited drawing conventions and the current complexity of many advanced CAD systems and the resulting high cost in effort required to take advantage of it's capability. As such, 'paper CAD' (or 2D CAD), has become the de-facto standard in AEC communication. The limited flexibility and completeness that was inherent in paper drawings are still present with 2D CAD. Even so, these limitations did not overshadow the advantages digital documentation provides:

- Storing of and accessing to large amounts of information
- Dynamic display

- Fast content searches
- Quick links to related documents
- Dynamic modification, updating and sharing of content

It is the sharing of content that drove the acceptance of 2D CAD within the AEC industry[14]. Even though the effort required to input information into a 2D CAD system was higher than on paper, the ability to modify and share that information increased its utility many fold [G. Black, 2002]. When this information was shared, however, it was a collection of lines that was shared, not the knowledge and understanding that created those lines. So, despite the advantages 2D CAD offered, the dependency on shared knowledge remained. Although 2D CAD's ability to increase the production and sharing of information provided incentive to integrate 2D CAD into the work process, the limitations of static/dynamic media came with it. To improve the situation, knowledge, not just graphics symbols, must be embedded within the medium; the document must become intelligent.

4.1 Smart Paper

Digital media offer a new set of affordances over paper, but they tend to present a more complex interface. Acting on and interpreting feedback from our actions with devices such as desktop computers often requires a great deal of learning and experience [A. Sellen, & R. Harper, 2001 p.18]. Donald Norman has suggested that this can be attributed to the fact that the affordances of a

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14 Kristine Fallon Associates, Inc (1999) Cad for Principals.

digital device are hidden, thus forcing an investment in learning how to access and implement their capabilities. Because digital devices can have various levels of affordances, they also tend to require various levels of learning. 2D CAD systems are viewed by many designers as sophisticated and expensive drafting devices which embody a passive/dynamic modality, but they are also, perceived as systems that can make the production and manipulation of lines easier and more efficient [KFA, 1999]. While it is actually easier is still debated, managing lines in a 2D CAD system is generally agreed to be more efficient especially with larger projects. Although an advance over paper, information is still passive thus making the 2D CAD system a sort of 'smart paper' system. By using the term smart paper, I am implying that the current way we present information (i.e. plans, elevations and sections) as separate but related documents fails to provide more than the ability to change the appearance of the information in the document and not the actual information.

4.2 Intelligent Objects for Intelligent Documents

The limitation of smart paper is also an advantage; the basis of the document is a collection of lines. Because a line is simple to describe in digital terms, exchanging lines between various CAD packages has become common. However, because only lines are exchanged, the higher order information of what the line represents or other information that is attached to those lines sometimes may be lost. In response to this limitation, the International Alliance for Interoperability (IAI) and more recently, major companies like Graphisoft, AutoDesk and Bentley, have joined in the effort to create a standard for information exchange [L. Khemlani, 2003, p.6]. This effort is currently known as Building Information Modeling (BIM). Like the defacto .dfx and .dwg digital file format standards for 2D line exchanges, the standard for BIM will most likely be driven by market forces. However once this standard becomes defined, its key will be the concept of intelligent objects.

Software objects are often used to model real-world objects. An object is a software bundle of related variables and methods[15]. An intelligent object is an entity within a CAD (BIM) document containing instructions that tell the host program about the object and what the object can do. These instructions allow the author to supply information to the viewer without explicitly creating that information. Since descriptions and functionality are provided, instead of lines and shapes, particular views and information is accessed dynamically reliving the sender from having to choose what information to include explicitly and what to abstract.

For example, using Industry Foundation Classes[16] (IFC) compliant building objects, a CAD user can reference a door object from a manufacturer's website. This door object might contain knowledge about a physical door it represents such as its name, functional capability, dimensions, finish, etc. The CAD software would then take this object and apply more information to it: its placement, swing

15 Sun Microsystems, Inc. The JavaTM Tutorial http://java.sun.com/docs/books/tutorial/java/concepts/ Last visited: June, 2003

16 The IFC system is a data representation standard and file format for defining architectural and constructional CAD graphic data as 3D real-world objects, mainly so that architectural CAD users can transfer design data to and fro between rival products with no compromises. [Geoff Harrod, aecXML & IFC http://www.cadinfo.net/editorial/aecxml.htm Last visited: July, 2003.

direction, relationship to other objects, hardware schedule, etc. The entire assembly could then be passed onto another program that performs cost estimating, scheduling or code analysis. Within a computer simulation, the door object would also have the ability to "operate" within the environment. For example, the door object could swing open, or a light could illuminate a room, or an air unit could indicate the capacity of airflow through its system. The door object could even determine whether something was placed in its path that impeded its proper operation.

Other programs, commonly known as 'agents', will be able to take these objects and make calculations about the building as a system, so that cost, load points, air exchanges, heat gain, and so on can be determined. If we can ask the object about itself, and have it react to other objects, then the door object can also "learn" about itself and its surroundings. Thus, a "door object" may "know" the history of where it has been placed and/or moved within the current project. In a future project the object could automatically place itself as a default.

An intelligent object can change how it displays itself depending on who is looking at it. This is very important because it illustrates the affordances of a dynamic display. Using the example of the door mentioned previously, the architect may only wish to see the architectural symbol for a door, the interior designer may wish to see it rendered completely in 3D, and the HVAC designer may not want anything displayed. Each discipline can decide how the door should be represented in his or her drawings, yet everyone is still referring to the same object.

The establishment of a BIM standard will hasten the creation of BIM compliant objects. Although many BIM objects will be created and made available via various services, (Sweet's Catalogue[17] from McGraw-Hill publishing, for example) a significant number of objects will still need to be created on a per-project basis. The amount of effort required to create these objects will be significant, especially in the beginning. To minimize this increase in effort, the creation of these objects must be shared among the various disciplines. As design disciplines collaborate with one other, each contributes its own objects to the building via the network. This innovation will provide a significant advancement in our ability to communicate. The door can be represented on many sheets, on many drawings, by many disciplines, and yet, should the door require modification, all those symbols would be automatically updated, saving significant labor and reducing error.

Although available, such sophisticated technology is not widely in use in the AEC industry. This can be attributed to the increased effort required to use this technology. Most of the tools that support intelligent objects require a significant investment in training and implementation. However, as we have seen with 2D CAD systems, as the effort required to use these tools lessens, the acceptance and proliferation of use will increase.

4.3 Intelligent Environments

Although exchanging intelligent documents, like those being discussed

17 http://sweets.construction.com/ Last visited: July, 2003.

around the BIM initiative will greatly enhance the utility of CAD; a display environment that can support such sophisticated objects must also be present. Such an environment must be able to support a wide range of display techniques: text, 2D, 3D multimedia and Virtual Environments[18] (VE). Although VE's are primarily used for presentation or exploration of very complex structures and systems, the increase in information and data quantity that will be generated from the integration of intelligent drawings will require a more dynamic viewing environment. Such an environment would reduce the resistance to data exploration and interaction by reducing the effort required to access and display increasingly large amounts of information. A VE can provide what Giddens calls a locale, the "use of space to provide the settings of interaction, the settings of interaction in turn being essential to specifying its contextuality" [A. Giddens, 1984]. This contextuality (sic) enhances clarity on the information being presented. Also, by involving the viewer in the orchestration of the unfolding environments, the viewer does not have to make as much of a cognitive leap to understand the environment that is being presented. There is little doubt that movement helps in our perception of objects. Frequently, drawings that make

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18 A VE is an environment or reality other than the one we are experiencing in traditional time/space. When Descartes described the evil demon bent on deceiving him about everything, including his own existence, he posed a problem that has tormented Western thought ever since. Descartes' concept of the separation of mind and body can serve as a metaphor for understanding VE. Reality is not observed, but interpreted by the observer through the senses. Creators of a VE replace normal sensory input with alternative sensory information, such as the classic 'brain-in-a-vat' proposition or Descartes' classic demon. For example, one sees an object because light bounces off of the object, enters the eye, stimulates cones and rods, and subsequently sends information to the visual system [S. Palmer 99]. If, somehow, the light patterns were changed so that the person would see another object, then his/her perceived reality would have changed. This is similar to how Decartes' demon could change what we see, or hear, or feel.

little sense when shown as stills are understandable when they are animated [S. Boyed, 1996].

It should be noted that the presence of a VE alone (without intelligent documents and distributed effort) does not validate the extra effort required to create it. During the 1990's a great deal of hype was generated around the potential of virtual environments. Unfortunately, it was centered on pretty pictures and virtual presence, rather then improving information creation and distribution for collaboration.

Many experiments and projects explored the issues and possibilities of VE; most focused on the display aspect. Dace Campbell developed an interesting project based on prototypical 3D construction drawings; embedding all the notations, symbols and dimensioning of 2D drawings into a 3D Web-viewable representation [J. Laiserin, 1999, pp. 6-10], as shown in Figure 8.

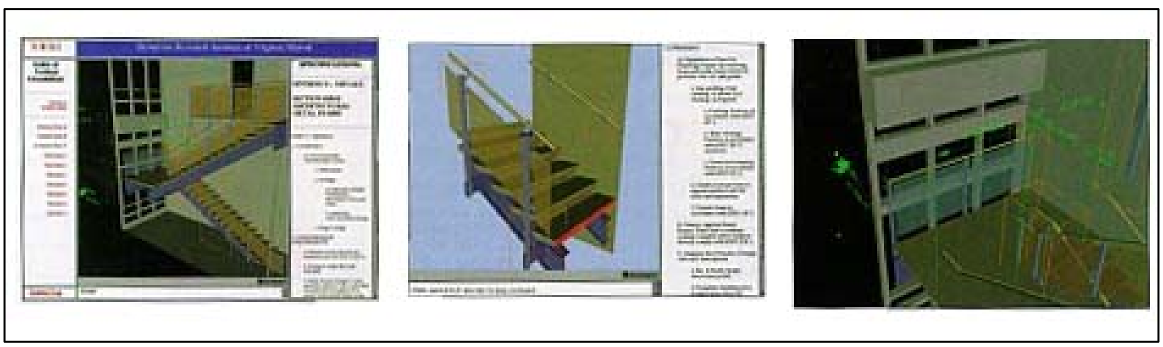

Figure 8: 3D construction document prototype by NBBJ.

Although these efforts help expand our understanding of displaying and exploring information, they ignore the extra effort required to create that environment. In Campbell's case, he created the environment himself and as such, the advantage of shared effort that is derived from collaboration was lost. Therefore, it could be argued that the added utility through improved accessibility of information may not have been justified.

Chapter 5. Collaborative Virtual Environments

The creation of a collaborative virtual environment[19] (CVE) requires a significant effort; including the development of 3D spatial models, intelligent objects, a viewing environment that can support active/dynamic displays and the training, equipment, and experience to use it. The returns on this effort through improved efficiency are realized not just in the fact that the viewer is able to walk through and interact with information, but also through an improved collaborative process of making a complete view[20] of the information (both spatial and statistical) available at all times, to all participants. As such, the author does not have to decide what should be seen, by whom, and in what format. The viewer, and/or the system, can seek out the information that they need and display it in a format that is most useful to them.

To illustrate this point, the software program 'Archville' was created. Archville allows collaborators to view 3D files they have created in conjunction with 3D files that were created by other users, in near real-time. This project demonstrates the benefits of having access to complete, up-to-date information in an active/dynamic environment. This program is also used as an instructional tool to demonstrate the concept described above.

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19 The general goal of CVEs is to create a place for people to interact. This is a goal all CVEs have in common. CVEs must create a 3 dimensional space for its users, because of the intention of providing a place for users to manage their activities (Harrison & Dourish, 1996).

20 Or at least, as much information the author wishes to share.

5.1 Archville as a New Media

Archville is designed to provide students with a functioning example of how an active/dynamic environment can support collaboration. In most design exercises, the design problem is contained in a vacuum, unaffected by the work of others. By going through the Archville exercise, students are exposed to the idea that design is derived from more than one person's grand concept. It is the result of collaboration by many people. The Archville program demonstrates through a pedagogical exercise the elements that digital media can employ:

- Explicit representation of the information
- An active/dynamic display that can support interacting with intelligent documents
- A standard information exchange format to ease the sharing of information
- Support for real-time and asynchronous communication
- Low effort of procurement and operation of the system

The Archville program demonstrates these elements, and by embedding this application within a pedagogical exercise, students are able to experience them.

Representation: Information is created in a 3D format and exported in the Virtual Reality Modeling Language[21] (VRML). Since the spatial information is

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21 The Virtual Reality Modeling Language (VRML) is a language for describing multi-user interactive simulations -- virtual worlds networked via the global Internet and hyperlinked within the World Wide Web. VRML is to 3D what HTML is to 2D. Rather than describing the location of 2D text and images on a page, VRML files describe the location of objects in a 3D space. As with HTML, VRML objects may be links to other objects, URLs, inline images, movies and sounds. In addition to the properties of HTML, VRML objects may be animated and interact with other objects and the user.

displayed as a whole and not through the filter of 2D abstraction, the viewer does not need to perform the same level of inference as with 2D information. Although there are limitations to VRML, this format demonstrates the advantages of more than just the communication of geometry; user interactions, autonomous actions and attributes are also contained within the representation.

Display: Using a VRML player (as well as JavaScript and Java) the viewer is able to dynamically explore the information presented. Point of view, level of detail and information filtering are controlled by the viewer. Also the viewer interacts with the information, accessing active information that otherwise may be difficult, if not impossible, to display using static media. The author can also embed instructions that are activated either autonomously or through user interaction. Students are able to attach information to objects, static information, simple rules for interaction and display, web pages and email links. Although this is simplistic, it does illustrate the advantages of including externally referenced information.

Standard Information Exchange: VRML provides a reasonably good standard for exchanging information. It demonstrates the advantages of communicating more than just geometry; user interactions, autonomous actions and attributes are also contained within the messages representation. Since most contemporary CAD systems can export data in the VRML format, it allows designers using various CAD programs (FormZ on Macintosh, solidWorks on UNIX and 3D Studio MAX on PC operating systems are some examples) to create and exchange information with each other for individual display or display within Archville. Unfortunately, not all CAD programs can import the VRML file format.

Communication: Archville is a distributed network system thus ensuring that latest available information is displayed. Every time Archville is accessed or refreshed, the system will access and integrate the latest information available on the servers. This ensures that the most recent information from each contributor is exchanged. Participants are also able to communicate in real-time with each other as well as to 'see' each other within the environment. Information for other collaborators can be placed in the environment if desired.

Effort: The level of effort required to implement and use a system will dictate whether that system is accepted and applied. Archville gathers, tests, and integrates the information automatically, requiring no significant additional effort by the author to share information. Managing the display of the information via an 'Address Book' which will be discussed in forth coming text, is also a simple process. This address book serves as a management tool that can allow or block information into the display. This aspect of distributed effort makes the trade-off of effort with regards to utility practical and acceptable for the exercise.

A good example of this collaborative capacity is an exercise in which students were asked to design a park with a path that connects to their adjacent neighbors. In addition, other students designed stationary follies[22] or objects that would move through the park. Students are able to work independently and still

22 Small buildings typically built for amusement.

view each other's work at any time without the effort of translating CAD formats. (One student performed her work using FormZ CAD package while the rest of the class used 3D Studio MAX). Although the requirement to connect paths proved difficult for beginning students, the true value and advantage of a CVE was in resolving the placement of follies and animation paths of the various objects. As the topography of the parks evolved, the planned animation paths of some objects required change. [23] Occasionally this meant that either a tree or a folly must be moved to prevent collisions. The result of such an action would have a "rippling effect" which at times would affect people's work in unexpected ways. For example, one student made a bridge that a car would travel across. It was determined that the bridge was too short to make the animation realistic; so the bridge was extended. Both students who designed the bridge and the car's animation were aware of the change. However, a student working on a folly version of the Bank of Hong Kong next to the bridge was not informed. When the change was made, the student working on the folly was able to see via the Archville system that his bank now occupied a section of the lake and part of the bridge. Because the first two students did not realize the impact of their changes; the student designing the folly would not have noted the problem until later in the exercise, if it was not for the fact that the Archville systems ensures that all participants have the latest information available at all times. This one event provided the entire class with a good example of the importance of the timely

23 Changing the elevation of an animated object was too advanced for a beginning ½ semester class.

information furnished in a dynamic 3D format.

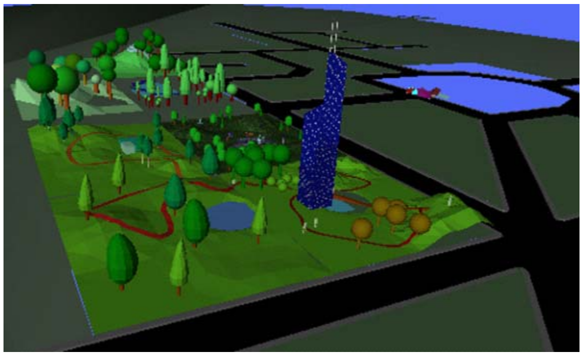

Figure 9: Folly intersecting lake and bridge.

Figure 10: Paths of 3 parks: checking for alignment.

5.2 The Archville Exercise

5.2.1 Cardboard City

The inspiration for Archville was a UC Berkeley design studio entitled 'The Cardboard City Exercise.' The intent of the exercise was to equip students with the basic proficiencies needed for their professional careers.

Figure 11: View of Cardboard City.

The Cardboard City exercise was given to third-year architecture students from the late 1970's until 1987. It was intended to teach them, among other things, how to deal with the creation of spaces as a collaborative form-making effort, rather than as an individualized effort. The exercise involved the design and physical construction of a cardboard 'city,' on 3'x 3' plots in a pre-designed 'urban landscape'. Students were assigned 'city' plots through a lottery system, and instructed to design a defined place for sitting.

The main requirement of the exercise was to insure that each students design vocabulary is similar to their neighbor. This requirement, together with group work effort, turned the Cardboard City project into an exercise in collaboration, as much as it was an exercise in physical design. Students learned the importance of communication and collaboration. They also learned the difficulty and enormous amount of effort that was required to coordinate with other contributors. Unfortunately, the creation of a Cardboard City by 75 students inflicted significant damage on the design studio facilities in terms of cardboard mess and gouged tables, floor tiles, and other surfaces.

5.2.2 Resurrecting the City

Figure 12: View of Archville in a VRML player with visibility Java applet.

The proliferation of computing technology, particularly CAD and the internet allows us to resurrect the Cardboard City exercise, using a CVE in lieu of cardboard. The Archville exercise is pedagogically similar to the Cardboard City exercise. Each student is given a plot in an urban landscape that was created in a CAD system. The students must design their 3D models to maintain some design consistency with their neighbors.

To support such an exercise using computers, an active/dynamic display environment is required. The Archville system provides this by allowing students to walk through the 'city' at any time to experience their design, as well as those done by others in the class. Because of the nature of VRML and objects defined within the environment, students can interact with the model and query information from it. Visitors can also interact with each other through the use of avatars and 'chat' windows. Finally, work that has been done in previous semesters need not be 'taken down' at the end of the exercise. Rather, buildings can be left where they are, creating a sense of history and a city that can grow and evolve, much like the real built environment. Since we are working within a virtual environment, more "land" can be created easily, making computer power and memory the only limits to the size of Archville.

5.3 The Archville System

Archville is a Web-based distributed CVE system[24] that allows multiple users to interact with multiple models at the same time. Using a combination of VRML, Java and JavaScript, the system can display information, such as text, images and geometry, in a single dynamic environment. It does so by calling files from distributed sources, integrating those files, and then displaying the information. For example, if a group of collaborators are interested in viewing a single file, then one file server would be sufficient. If more then one file is to be viewed, then

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24 The idea behind distributed CVE is very simple; a simulated world is stored not on one computer system, but on several. The computers are connected over a network (typically the global Internet) and people using those computers are able to interact in real time, sharing the same data in the same virtual world. This distributed architecture is also referred to as Federated architecture.

the viewers must choose between one information source and another. A distributed system will access all information sources and the same time and display that information in an integrated fashion.

In the application of Archville, a small file is downloaded from a central location with code (VRML and Java) that retrieves, integrates and displays information on the client’s machine. This information is also exposed to allow special programs from the client to perform operations on that data.

Single Source information Access | **Single Source Access with more then one source** | **Distributed Information Access**

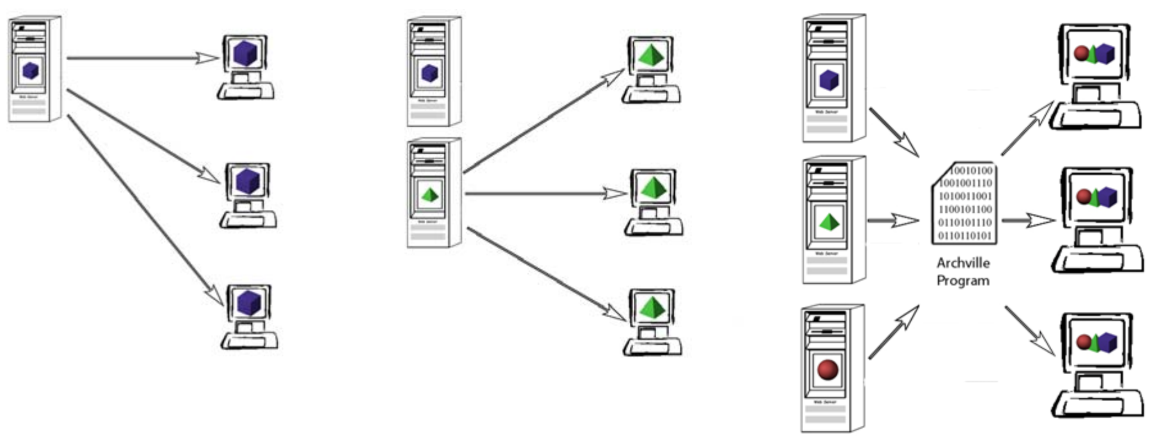

Figure 13: Distributed Computing Diagram

A model of the urban layout is placed on the Web in the format of the 3D tool employed during a given semester (typically 3D Studio MAX). It is then downloaded or accessed by the students’ computers. Students locate the site to which they are assigned and design their own buildings within its borders. When the students are finished with their designs, they ‘post’ them by saving the files in a directory that is accessible to the Archville program through the Internet. The URL of each file is entered in the ‘Address Book’ so that the files can be loaded into the combined scene. When the student accesses Archville, his or her model is displayed along with the buildings designed by the other students.

Although this commonality is not a 'standard' like that which is being developed in the recent BIM movement, the variety of systems that can output the VRML format demonstrates the idea of sharing information outside of a particular CAD package. One advantage to using 3D Studio MAX to create Archville sites is its ability to create some VRML nodes (extended behaviors) within the modeling program itself. Many of these nodes support the attachment of scripts to 3D objects, so that animations can be started based on the viewer's location or by using a mouse to click on an object. For example, in one Archville model, the elevators in the office buildings are programmed to take the viewer to the floor selected on the elevator control panel. Once there, a VRML scene which depicts interior of the selected floor is automatically loaded.

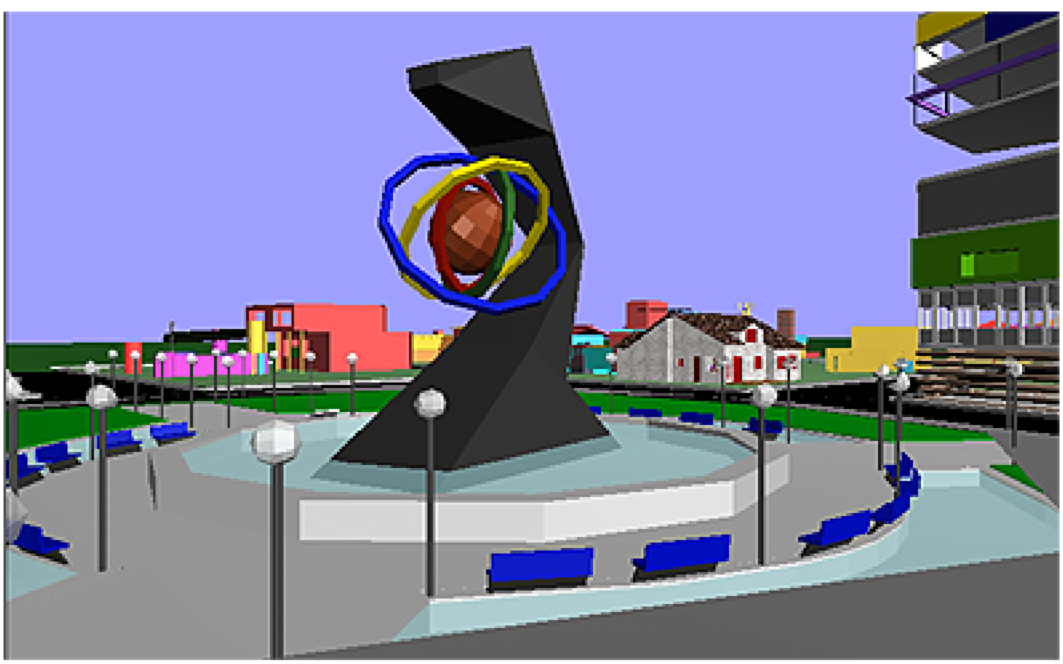

Figure 14: View of the Central Park and Sculpture.

Another example is the sculpture in Archville's central park. One student placed two buttons within his model. One button allows a set of rings to move at the center of the sculpture. The other button takes the viewer to that student's Web page (Figure 14). Because the tools used to create this functionality are embedded into the CAD program, extra effort is not required to extend the model's functionality. Recently, students have been asked to place 'mail boxes' in front of their buildings so that the viewer can email the author.

When the Archville program first loads, the base geometry of land and urban infrastructure is loaded. At the same time, a Java applet is called that presents buttons which load different collections of objects. Once a collection has been loaded, the same button then controls the visibility of the collection.

For example, the students can either load only those files that were created by their classmates or, alternately, they can load files created during previous semesters. Another program that can be loaded is a Java applet called Vnet, created by Stephen White. This program creates a presence in the virtual scene with an avatar representing the viewer. Included in this applet is a chat box that allows collaborators to communicate with each other.

Figure 15: Vnet chat box within Archville. Avatar in center.

5.3.1 How Does Archville Work?

The heart of the Archville system is a small set of files referred to as the Address Book. These files contain, in a structured manner, the URL (Uniform Resource Locator) address of each student who is involved in the project. As each file is read from the address book, it is loaded through the Internet and the VRML viewer integrates the file's content into the composite scene. This continues until all the files have been loaded. If a file cannot be found, the visitor is alerted and the program then goes on to the next file.

The file that links the work of individual students with the site is a simple HTML file that in turn loads a VRML file and any Java applets that are to be used in the scene. The HTML file (Archville.html) looks like this:

```
<HTML>
….
<BODY>
<embed src=”Root.wrl”  width= ”600”  height = “400”
<APPLET CODE=”visabilityControl.class” WIDTH=600 HEIGHT=100 maytag></APPLET>
…. </BODY> </HTML>
```

The third statement loads the VRML viewer and the VRML file called Root. The next line brings up a Java program used to load/hide/unhide groups of objects within Archville.

The VRML file (Root.wrl) that is loaded looks like this:

```
#VRML V2.0 utf8
DEF Start Viewpoint {
    description "one"
    position 40 5 10
    orientation 0 1 0 0
}
Background {
    skyColor [0.62353 0.62353 1, ]
    groundColor [.3 .4 1, ]
}
DirectionalLight {
  ambientIntensity  1
```

```
 color          1 1 1
 direction       -0.612 -0.4598 -0.6435
 intensity       .7
 on             TRUE
}
Inline { url "streets.wrl" }
Inline { url "treasureIsland.wrl" }
Inline { url “groupA.wrl” }
Inline { url “groupB.wrl” }
Inline { url “groupC.wrl” }
…
```

This code sets up the basic environment of an initial viewpoint, lights, and background. The Inline statements load the street geometry and the surrounding landscape. The other Inline statements are the Address Books of the different groups contributing to Archville.

The URL address of each student is placed into a file based on the student’s subgroup. A typical group file (groupA.wrl) looks like this:

```
#VRML V2.0 utf8
# Group A, Spring Semester
Inline { url “http://…berkeley.edu/~studenta/plot12.wrl” }
Inline { url “http://…berkeley.edu/~studentb/myhouse.wrl” }
Inline { url “http://…berkeley.edu/~studentc/assignment4.wrl” }
…
```

Basically, a nested file system is created as seen in Figure 16.

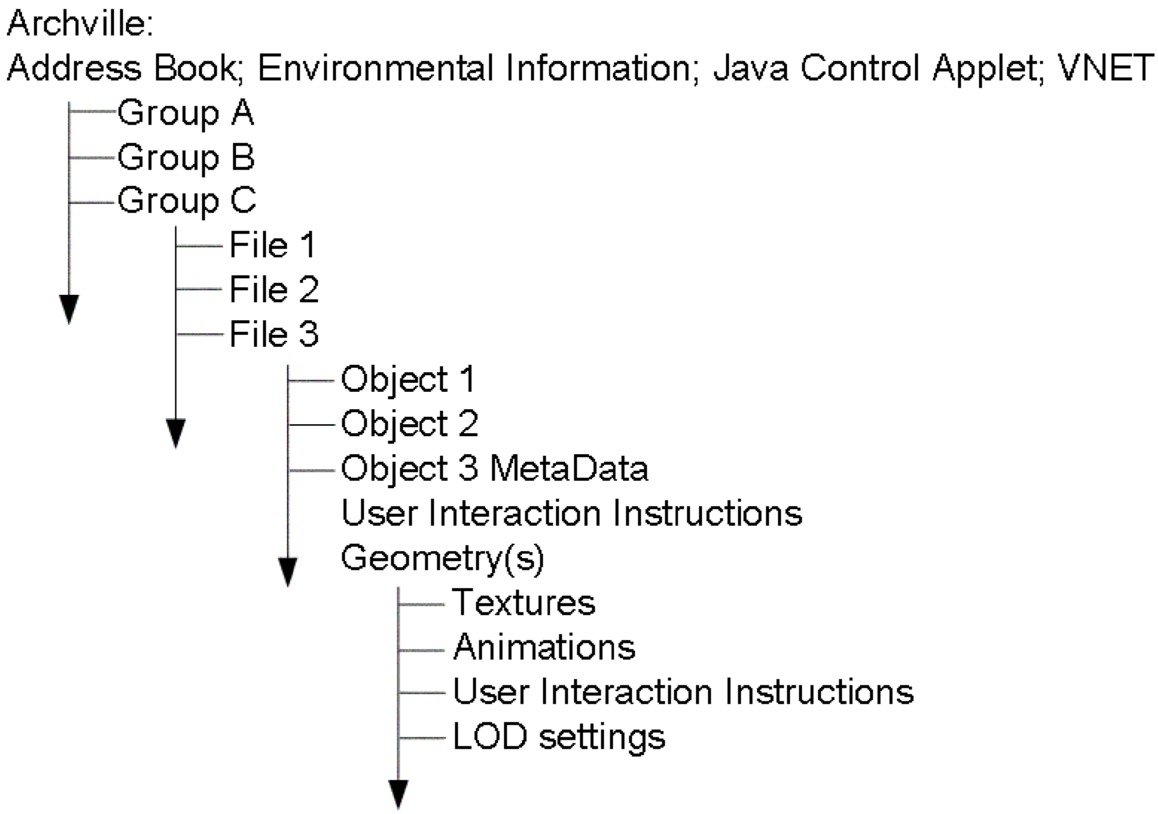

Figure 16: Archville Nested Meta Structure.

5.3.2 Pedagogy

Although Archville is used in two courses, the collaborative aspect of the exercise is only explored in the course ‘Introduction to 3D Modeling’. This is a 7-week course that meets once a week and is given twice each semester with an average enrollment of 17 students per half-semester. Although students spend only three weeks on average performing the exercise, they still gain valuable hand-on experience in collaboration and the impact communication tools have on that collaboration.

The exercise begins with a quick explanation of collaboration in design. Students also receive a short history of manual drawing methods and how this affects the way we use CAD systems. Further explained is the current state of CAD tools and how they are used in a collaborative project. This is done to insure that the students appreciate that computer systems are more than tools used to create 3D models. After a short explanation of Archville, the exercise is begun.

Students are assigned a plot in the landscape on which they are to build. They are then shown how to place an external reference of that landscape into their CAD systems, which is an example of referencing an object within a library. The 3D model for the urban landscape resides on an external server, and any changes made to the streets are automatically updated in the students' models.

Typically the students are allowed to build anything they wish and encouraged to let their imaginations run free, as long as the model does not exceed 2000 polygons.[25] A wide range of designs are created by the students including common-looking houses, interesting sculptures, and even a tree house (Figure 17).

---

25 The 2000 polygon restriction was based on common computing power available in 1998. The power of today's machines invalidates that limitation.

In order to encourage quick and highly abstract designs, the first part of the assignment is due the same day the assignment is given. Students are then shown how to post their VRML models to a web site and look for their model when they open Archville. The end result is an urban setting that is populated within hours.

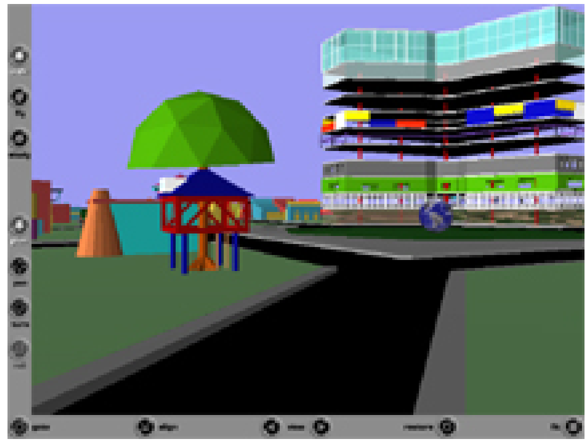

Figure 17: Tree House.

After one week, students are told that there must be an agreed-upon design element common to all of their work. This means that they must adapt their design, and/or convince their neighbors to change theirs. Normally, color, scale and language is used to accomplish this. Local neighbors are those students whose properties are directly across from, and adjacent to, the student's plot. The idea is for students to experience the challenge and frustration of having a moving target during the design phase. As each student makes a change to their design, they base that change on what their neighbor has done. Unfortunately, the neighbor is also making changes based on another neighbor's design. Very quickly, the students realize that they must not only deal with the immediate design constraints of their three neighbors, but also the design constraints those neighbors are working with. In time, students realize that a constant awareness of local and global changes in design is the only way to keep up with the rapidly changing landscape. An example of this rapid change is illustrated in Figure 18.

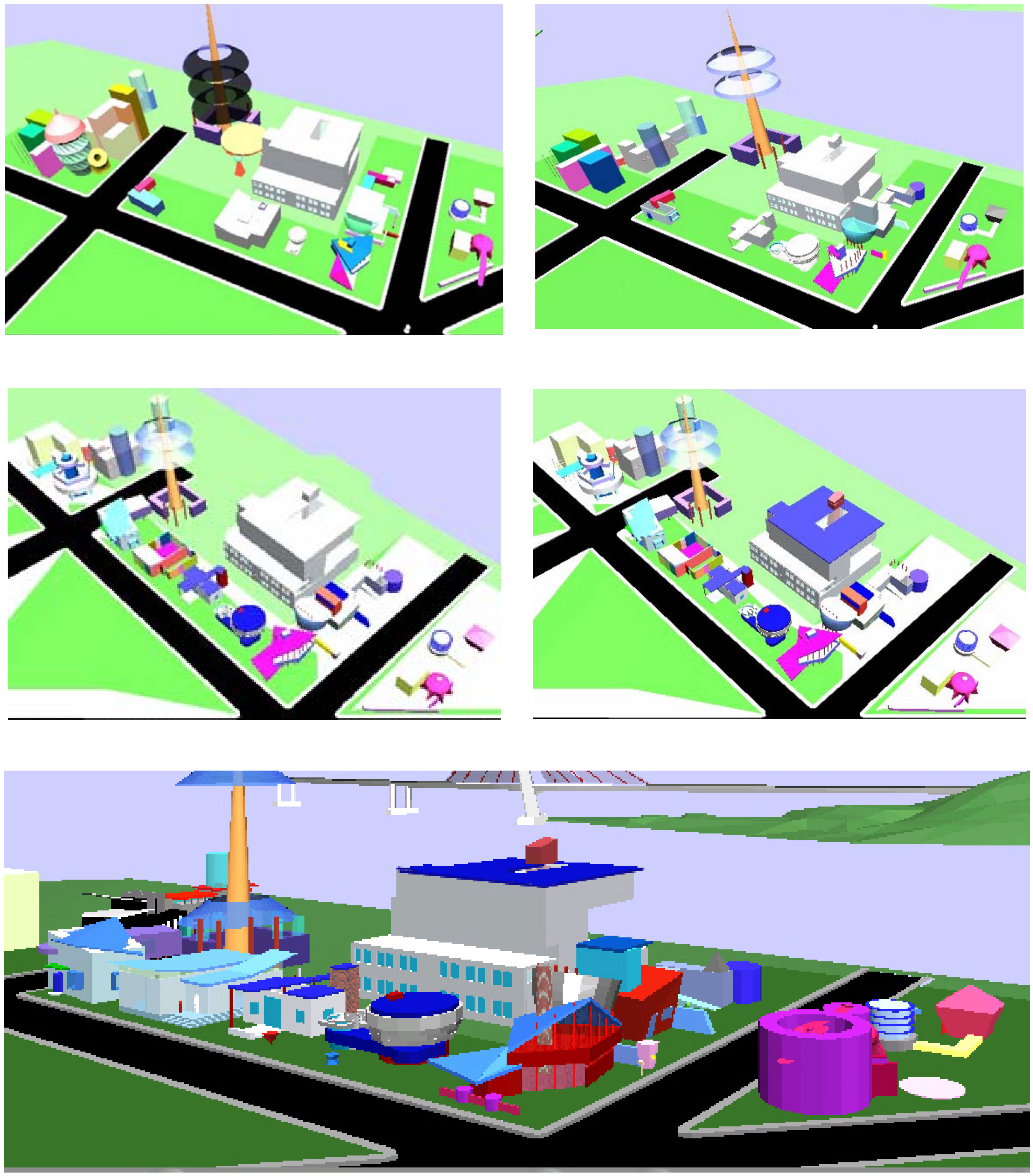

Figure 18: During each exercise, a screen shot of Archville is taken every 15 minutes to record the changes. As one can see in these images below, a design change in one area (in this case, roof color) very quickly echoed throughout the neighborhood. Towards the end of the exercise, one can see the color red for block shapes beginning to arise.

5.3.3 Pedagogical observation on the exercise

Students are surprised at the difficulty of working with others on a project, especially one that progresses as quickly as Archville. Of course, it is this understanding, as well as the benefits of having a collaborative virtual environment, that Archville is meant to demonstrate. Although creating a large virtual environment requires significant work, collaboration in a virtual world can accomplish this in a short amount of time. Archville serves as a highly instructive example of different professionals working together to create something that is too large and diverse for one person to create alone. Although in our case each student is creating the same thing (a building), this idea is not hard to expand into different specialties (Engineers, HVAC, etc.) working on a single structure.

5.3.4 What was Learned?

The Archville exercise demonstrates to students how we can use computing and the Internet to design collaboratively. It also points out the need to have correct up-to-date information when working on collaborative projects because of the dynamic nature of the design process. Students also experience the benefits that an active/dynamic environment can provide through: (1) exchanging 3D information, (2) being able to view changes to a design as soon as they are available, (3) interacting with fellow collaborators in real-time from remote locations, and (4) accessing more then just spatial information from within the model, the experience of creating a neighborhood or a large complex building with far less effort than required with tradition media. By understanding that CAD can be more than an electronic drafting device or a digital paint brush, there will be an expectation and demand that practice, as well as tools, adapts to take advantage of this possibility [Y. Kalay, 2001, p.6].

Chapter 6 Conclusion

> "We wanted to know if the average firm just didn't take full advantage of the tools available, or if the tools themselves were inadequate," remarks Fallon. "We found that both were true". CAD for Principals.

Technologies are not planned, but rather they emerge from our culture as it learns and builds. Perhaps because of this, their effect on our practices is rarely guided by reflection. More often, as our tools are transformed by technology, practices adapt to the changing context. There are times when the effort required to make those changes are not validated. " (CAD software) should be easy to use, and we will usually forgo some of the more sophisticated features of one package if another will perform 90% of the everyday tasks more simply" [J. Pringle, 1992, p.80].

The automation of drafting and electronic communication has increased the speed at which we communicate information. Although these clerical advancements have increased production capability, they still have not improved the basic mode of collaboration within the AEC industry. The next advancement in communication must be by improving 'what' is communicated and 'how' it is communicated. The 'what' includes intelligent documents that not only contain spatial information, but also define relationships and attributes that allow other programs to understand and use this information. The 'how' refers to highly distributed networks that allow information exchange, updates and references to occur in near real-time and a display environment that can support this swift exchange of information exchange and intelligent documents. Collaborative design includes more than simple document exchange; it compiles, adds value to, and conducts dialogues over sophisticated artifacts [M. McCulluogh, & R. Hoinkes, 1995].

In order to guide these changes in CAD and practice, efforts must be made not only to espouse the benefits of new media, but also to demonstrate what this media can offer. Archville, product and pedagogy, serves to provide the experience of a collaborative virtual environment.

The additional effort (or perceived effort) to employ a new medium must demonstrate improvements in capability and in efficiency. In addition, this perception must be generally accepted in order to allow effective collaboration. The most difficult obstacles, however, are inherent to the industry, involving a large number of disparate organizations that cooperatively participate in the planning, design, and construction process [S. Fenves et al,. 1994]. Trying to change an industry's way of thinking is not easy nor will it happen overnight. It is not uncommon that new technologies are used inappropriately; just as the first cars were considered horseless carriages and the first films were created with a camera positioned in one place, the AEC industry continues to work with a paradigm that was forced upon us by the limitations of paper. Only with the combination of awareness and improved tools can the additional utility of new digital media overcome the additional effort required to implement it. Only then will revolutionary change take place in AEC via collaborative communication.

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