BUILDING INFORMATION MODELING

A MINIMUM MATHEMATICAL CONFIGURATION

A Thesis

by

RUCHIKA BHANDARE

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2012

Major Subject: Construction Management

Building Information Modeling a Minimum Mathematical Configuration

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Approved by:

Chair of Committee,	John M. Nichols
Committee Members,	Nancy L. Holland
	Wei Yan
Head of Department,	Joseph P. Horlen

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ABSTRACT

Building Information Modeling - A Minimum Mathematical Configuration.

(August 2012)

Ruchika Bhandare, B. Arch, Maulana Azad National Institute of Technology, Bhopal, India

Chair of Advisory Committee: Dr. John M. Nichols

In the current context, the standardization of building construction is not limited to a specific country or to a specific building code. Trade globalization has emphasized the need for standardization in the process of exchange of design information, whether it is in the form of drawings or documents. Building Information Modeling is the latest transformational technology that supports interactive development of design information for buildings.

No single Building Information Modeling software package is used in the Architecture Engineering Construction and Facilities Management industries, which is strength as new ideas develop, but a hindrance as the new ideas flow at a different pace into the various programs. The standards divergence of various software results in a limited ability to exchange data between and within projects, especially one sees the difficulty in moving data from one program to another. The Document eXchange File format represents an early attempt to standardize the exchange of drawing information by Autodesk. However, the data was limited to geometric data required for the production of plotted drawings.

Metadata in a Building Information Model provides a method to add information to the basic geometric configuration provided in a Document eXchange File. Building Information Model programs use data structures to define *smart objects* that encapsulate building data in a searchable and robust format. Due to the complexity of building designs eXtensible Markup Language schemas of three dimensional models are often large files that can contain considerable amounts of superfluous information.

The aim of this research is to exclude all the superfluous information from the design information and determine the absolute minimum information required to execute the construction of a project. A plain concrete beam element was used as the case study for this research. The results show that a minimal information schema can be developed for a simple building element. Further research is required on more complex elements.

DEDICATION

To my family

ACKNOWLEDGEMENTS

I would like to thank my committee chair, Dr. John M. Nichols, and my committee members, Dr. Nancy Holland and Dr. Wei Yan, for their guidance and support throughout the course of this research.

Thanks also go to my friends and colleagues and the department faculty and staff for making my time at Texas A&M University a great experience. I especially want to extend my gratitude to my batch mates Sheetal Goel, Nishi Lagoo, Salil Jawadekar and Xun Zhou who sincerely participated in my study and helped me efficiently collect the data. In addition, I also want to thank Mr. Chuck Tedrick, Digital Fabrications Manager at Architectural Ranch, Texas A&M University for his invaluable time and help and support in this study.

Finally, thanks to my family for their encouragement and also to all of my friends, especially Jatin Singala, without whom this research would not have been accomplished.

NOMENCLATURE

BIM	Building Information Modeling
IFC	Industry Foundation Classes
XML	eXtensible Markup Language
CAD	Computer Aided Design
AEC-FM	Architecture/Engineering/Construction-Facilities Management
DXF	Document eXchange File
IAI	International Alliance for Interoperability
AIA	American Institute of Architects
2-D	2-Dimensional
3-D	3-Dimensional
SPF	Step Physical File
STEP	Standard for Exchange for Product
IPD	Integrated Project Delivery
SGML	Standard Generalized Markup Language
LOFT	The act of marking out boat plans at full scale
R^2	A Cartesian Space of two dimension defined by real numbers (Borowski & Borwein, 1989)

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CHAPTER I

INTRODUCTION

BACKGROUND

The aim of legal construction documents is to provide an acceptable level of information required to construct a building to an acceptable standard and to hopefully meet the requirements of the owner. As architecture has evolved as a profession and the design of buildings has become more complex than simple stone dwelling, the need for drawn and written communication between the designer and the builder increased. Constraints like a builder's ability or technological insufficiency also led to conflicts in user expectations and building execution. Solving these issues needs a thorough understanding of contracts and precise presentation construction information. This level of information is rarely available, leading to extensive construction litigation.

This study looks to establish a minimum level of mathematical information to document a concrete beam element in a markup language.

OBJECTIVE

The research objective is to establish an acceptable level of information required to construct a building element and place the data into a markup language format. The key is thus eliminating the superfluous information from the data stored in building information model files, such as document exchange format (DXF)(Autodesk Inc., 2012a).

This thesis follows the style of *Adult Education Quarterly*.

HYPOTHESES

The hypothesis of the study is a minimal markup language data set can be defined to create a concrete beam element containing all information required for construction by other than the designer.

LIMITATIONS

The study limitations are:

1. The study is limited to the task of building a sample plain concrete beam
2. The participants are chosen from the pool of graduate level students of the Construction Science Department of Texas A&M University, although the selection cannot be considered random
3. The strength of the beam is not relevant to the study
4. The results will be expressed in XML format as the formal markup language.

SIGNIFICANCE

This would minimize the effort of drafting and would try to limit the role of the designer to one of primary design programming. This would foster interoperability and facilitate easier ways of data exchange. This research would define the minimum information required by a building information model's database to design a building up to a legally acceptable standard.

This step would provide a cost efficient way to minimize the building prices on the cost of human error and would reduce the time, energy and man force required for the preparation of drawings. This would help to identify the input of the architect, engineer and construction specialists in the preparation of construction drawings during the facility construction. This research can majorly benefit the market segment of construction industry involved in construction of projects which involve design replication of a prototype model such as residential community, row housing, and dormitories.

CHAPTER II

LITERATURE REVIEW

INTRODUCTION

This literature review outlines the relevant information about the development of modern contract documentation from the earliest stages of urban development in the eastern Mediterranean region (Glowacki & Dafedar, 2010) to the modern era (Richard & Elena, 2006). In this section, the changing nature of design presentation techniques is discussed from the basics of geometry, describing its application in production of hand drawings, up to the interpretation of applied geometry in CAD software, as currently used in Building Information Modeling tools for a wide variety of tasks including housing structures analysis in Indonesia (refer to Figure 1) (J. M. Nichols, 2011).

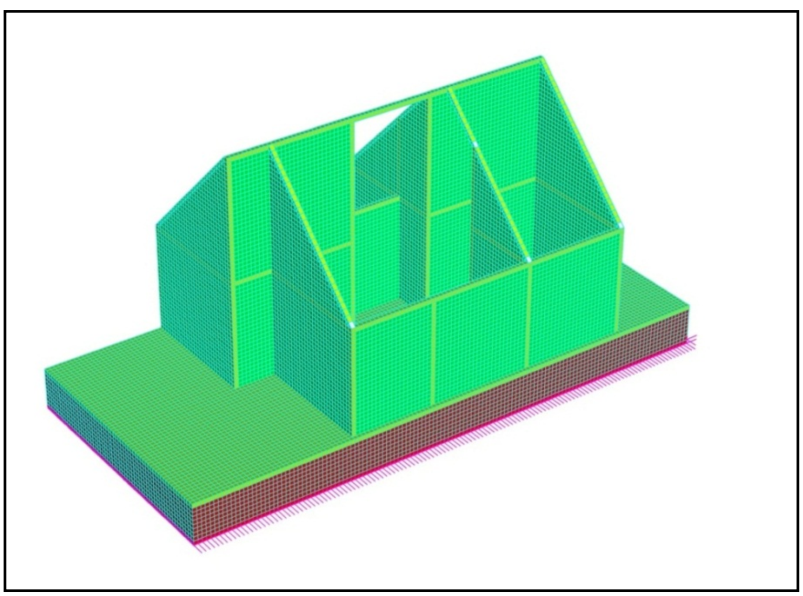

Figure 1. Indonesian home structure for analysis

The development of the Indonesian home model for finite element analysis and Narbonne Cathedral finite element model analysis by A. Nichols and others showed the extreme difficulty in transferring the Revit Building Information model data into an analysis package, in this case Strand 7 (G+D Computing, 1993; A. B. Nichols, 2010; A. B. Nichols, Paul, & Nichols, 2010; A. B. Nichols, Paul, & Nichols, 2011; Strand7 Pty. Ltd., 2009). The earlier research built upon Narbonne Cathedral work completed by Paul (1991). This earlier work provided the kernel idea for this current study.

The sections of the literature review are:

- definitions
- evolution of contract documents
- construction contract documents
- transition in medium of presentation for drawings
- adoption of computer aided design in construction
- advantages of computer aided design for producing construction drawings
- markup languages

DEFINITIONS

Contract terms of interest to this research are:

Agreement: A negotiated and typically legally binding arrangement between parties as to a course of action (New Hampshire Department of Transportation., 2004).

Bill of quantities: In traditional contracting, a contract document comprising a list of the materials required for the works and their estimated quantities, produced by the quantity surveyor (New Hampshire Department of Transportation., 2004).

Errors: Errors are inconsistencies or omissions discovered during studying of the drawings, examining site conditions and general observation. If the contractor discovers any errors they must be reported “promptly” to the Architect or the equivalent party to the contract (Holden, 2002). This of course is a coverall clause aimed at protecting the architect or engineer. This is often one of the criticisms of AIA and equivalent documents, they are not necessarily unbiased.

General conditions of contract: The general conditions form of the contract sets forth the responsibilities of the owner, contractor and architect during the construction (AIA., 2007b).

Insurance: A promise of compensation for specific potential future losses in exchange for a periodic payment.

Schedules: A plan for carrying out an activity or a deliverable, predicting its intended time of occurrence, as explained by Newitt (2009) in his seminal text.

Special conditions of contract: These Special Conditions of Contract delete, amend or add to the clauses in the General Conditions of Contract. In the event of an inconsistency, these Special Conditions of Contract shall take precedence over the General Conditions of Contract to the extent of that inconsistency (AIA., 2007a).

Specifications: The requirements which are to be followed in the construction of the highway. The standard specifications, supplemental specifications, special provisions, and all written or printed agreements and instructions that pertain to the method and manner of performing the work, or to the quantity and quality of the material to be furnished under the contract (New Hampshire Department of Transportation., 2004).

EVOLUTION OF CONTRACT DOCUMENTS

If one decides to build something, such as a bookcase, then there is no need for plans if one knows exactly what is required to complete the work. The three difficulties of modern life is the extreme level of specialization of the human environment, the limited range of products available for a given application and the need to determine dimensions. Even construction as simple as a wooden boat can be problematic. Boats similar to the one shown in Figure 2, has been built for millennia throughout the world. This boat has been constructed in the woodshop in the College of Architecture, twice at full scale and at least three times as a quarter scale model. The construction has proved to be both problematic and difficult for the construction science students, both graduate and undergraduate.

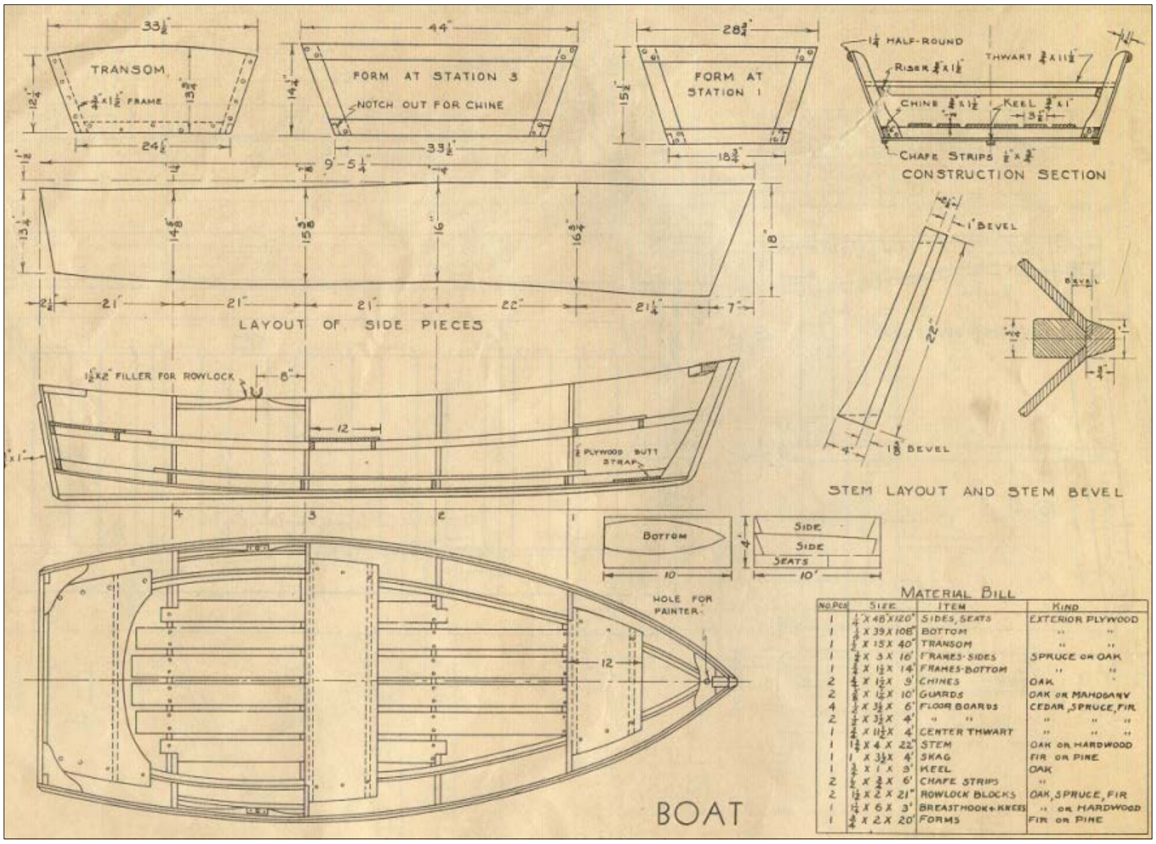

Figure 2. Small timber boat (after Douglas and Roberts (1936))

The boat plan upon first inspection appears to be complete and in terms of the overall construction concept it is complete, but in terms of the dimensional geometry it has some significant errors that are insidious and not evident until the plan is translated in to building information modeling software and the dimensional problems require decisions to be made to resolve the problems. In the normal course of building a timber boat, the plans are lofted and the lofter makes the necessary dimensional corrections, however in the building information modeling the designer needs to make decisions on the immutable lengths and the mutable lengths. In the case of this boat design, the original designer has set the lengths along the sheer line of the boat side at a regular interval, in this case 21 inches (533 mm) on average. This introduces a variation in the individual length between the centerline station points numbered 1 to 5, which should be a simple grid for ease of construction. As simple a grid as possible is observed generally in most major building contractual documents.

As Nichols (2012b) noted the first construction took fifteen undergraduate students a total of eight weeks of part time work. A graduate class, who were instructed to minimize the construction time to one day (if possible), spent twelve weeks getting a set of computer aided construction plans and working out an acceptable building technique. The cost of construction is one of the most immutable costs; it does not change in real terms over the long term. The change that is ultimately needed in the industry is an automated design process that minimizes human intervention, which only slows up the process. The natural human desire in construction is to interfere, so it is done to the human's desire.

The starting point for construction is the early villages, towns and cities of the Asian and Eastern Mediterranean regions, with the first code of acceptable conduct being Hammurabi (Johns, 1904). In essence the code is essentially similar to the concept of an eye for an eye.

Figure 3 shows an example of a flat roofed stone housing in Jerusalem common during biblical times. One sees a similar style of housing in Crete in the modern time (Glowacki & Dafedar, 2010).

Figure 3. Stone houses with flat roof (after Gilbert and Beers (2012))

One must assume that is likely that no drawings or very rudimentary drawing or sketches existed for this type of building construction, and it is mere conjecture to estimate how the sizes of the room were decided between the owner and the builder, other than the likely limit of the roof timbers (Glowacki & Dafedar, 2010).

The key point is that generally buildings in these types of villages are very similar, which means that the construction knowledge is human based and probably strongly reliant on verbal communication. It is not easily possible to determine the medium used for production of any construction documents used for this type of construction due to the paucity of records. It is considered that agreement by contract during this period was either verbally agreed or simple document ("Letter", c. 2000 BC), such as this letter on building stone.

In the end, either the builder agreed to build the facility for its client involving a monetary or other transaction or the work was self-performed is the only reasonable conclusion. Hammurabi's Code of Laws is one of the earliest known building codes which bound the builder to perform and the client to pay for the received services (Johns, 1904).

Modern construction contract documents (Lesser & Bacon, 2008) are included in a construction contract. A set of construction contract typically includes:

1. owner-contractor agreement, usually standard (AIA., 2007a)
2. conditions of the contract, such as (AIA., 2007b)
3. special conditions of contract, typically job based
4. drawings, both new and standard
5. specifications, both new and standard
6. addenda, modifications, and scope of changes
7. together with any other item stipulated as being specifically included

Submission of a construction document for tender or bidding purposes is the final step in the design and bidding phase within the project delivery model. This phase focuses upon finalizing all drawings and specifications for building systems, site utilities, along with components that will form the basis for the project's construction documents. A final set of comprehensive construction documents provides specifications and drawings sufficiently complete to support the bidder's price, obtain necessary permits, and construct the project (UMN, 2012).

At least three parties are involved generally in preparation of the contract documents, the design team, construction team and the owner overseeing this process, as shown in Figure 4.

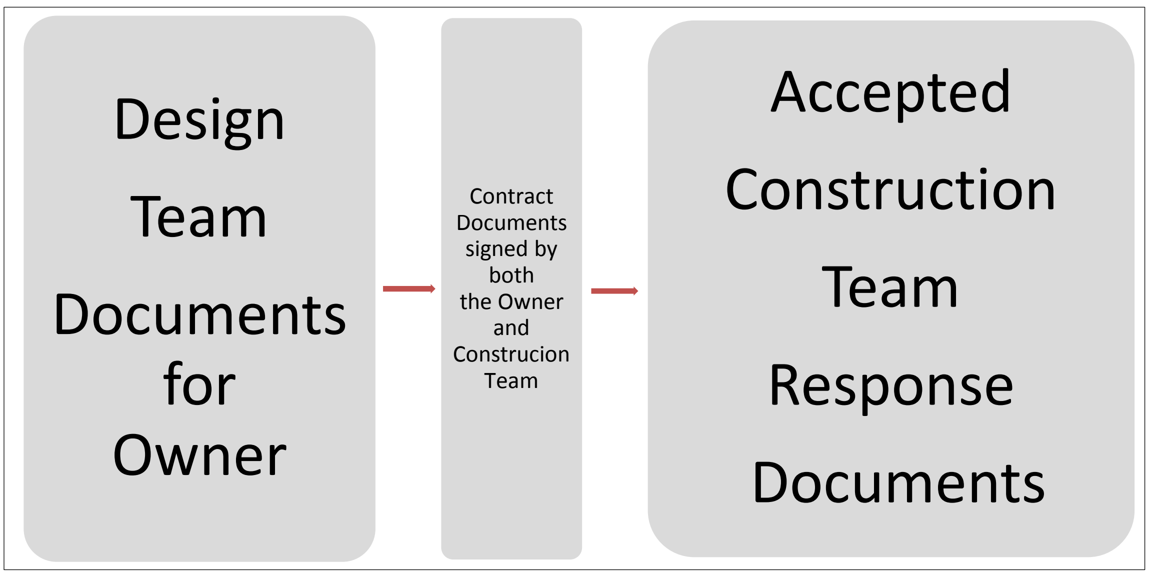

Figure 4. Contract document process

The documents represent the legal contract, errors or omissions in the document can generate litigation, change orders and cost variations. The legal process provides protection for both parties, but provides a hindrance in the formal communication required to resolve issues quickly and in an economically efficient manner. This type of hindrance is not evident in self-performed work, except as inherent in any internal company communication. The other ethical issue with self-performed work is cost control particularly in a monopoly situation

Ultimately, the contract documents for construction defines the scope of information needed for construction agreed upon by the design and construction team to deliver the facility as per the owner’s requirement, binding the owner to pay for the services wanted for the task. Modern computing has changed the face of document preparation, unfortunately the brute force work required on the site has been changed little in the last fifty years, when compared to the results of Moore’s law (Intel., 2005) there is limited productivity advancements in the last fifty years.

CONSTRUCTION CONTRACT DOCUMENTS

The development of increasingly complex urban infrastructure and the relatively high cost of labor in some parts of the world provide the driving mechanism to minimize costs. One of the methods to minimize costs is to ensure an accurate and timely set of contract documents for the undertaken project. A set of contract documents generally comprises of agreement, general conditions of contract, special conditions of contract, drawings, specifications, bill of quantities, schedules, and insurance as explained earlier.

In case of simple construction such as a corrugation shed (Figure 5) or a simple building, the builder might have prototype projects or sample construction drawings that can be shown to the owner before the actual preparation of construction documents. If agreed by the owner, these construction documents could be used for construction barely changing the set of contract documents, except to determine location.

Figure 5. Corrugated steel sheet shed (after Bebco Industries. (2012))

But the owner might indicate different requirements, as it might be in a different location. Thus every project requires a unique set of construction agreement, even for the installation of a simple new valve in a house (J.M. Nichols, 2012a).

For more complex projects, there are a number of professional organizations, such as American Institute of Architects (AIA), who define different types of contract document suitable to specific projects (AIA., 2007a and 2007b). The essential point of the contract documents is to provide a legal basis of agreement between the parties for the project execution. Thus execution of a project requires a transfer of information from the owner to the designer to the builder using the drawings and the construction documents. The construction documents are one of the fundamental components of a contract as it contains the medium to exchange information (Lesser & Bacon, 2008).

During the 19th century, often the design team produced a single set of drawings as no method existed to copy the drawings with ease and speed (Suermann, 2009). With rapid development of technology such as CAD, production of multiple copies of a set of drawings is much simpler, than hand tracing the details. CAD also facilitates the production and approval of drawings submitted by the specialty-contractors/sub-contractors (Jones, 2009). The key element is this transition from hand drawn to computer aided design, which has occurred over a five thousand year period, with the greatest changes in the last fifty years.

TRANSITION IN MEDIUM OF DRAWING PRESENTATION

Assyrian to Roman Period Drafting

The development of mathematics for building can be traced in part to the clay plates of the Assyrian people (Allen, 2002). Geometry is one of the oldest mathematical sciences (Cencelj, Dydak, Vavpetič, & Virk, 2012; Kaplan & Lewis, 1971; Levy, Chen, Lin, & Yang, 2004). The basics of early building design techniques, as is evident in the Assyrian documents, involve geometry, including factors such as:

- shape
- size
- relative position of figures and elements

- properties of space

Figure 6 shows the simplest geometric development to establish entities, such as rafter length on non-flat roof construction.

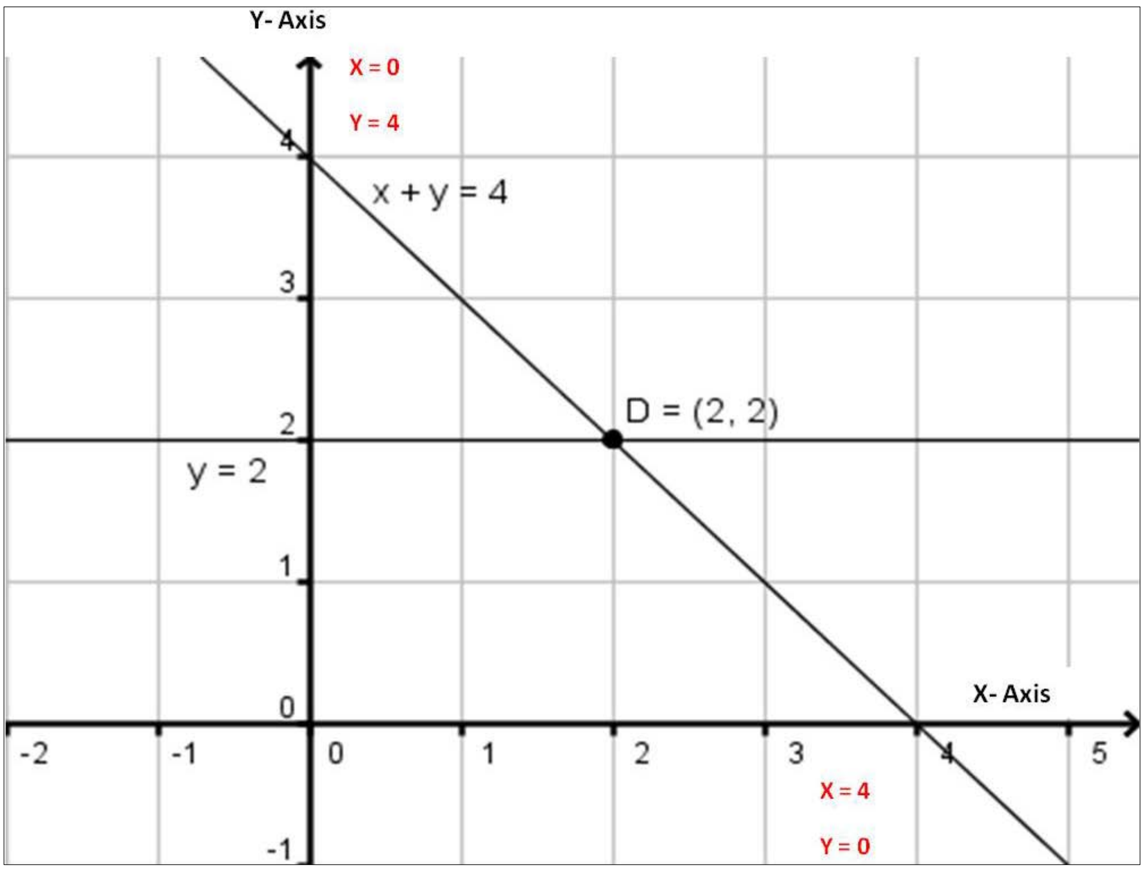

Figure 6. Geometric representation of information

As with the boat project, shown in Figure 2, the purpose of the plans is to provide the geometry for construction and some details as shown for a test assemblage in Figure 7 (J. M. Nichols, 2000). In this case the drawing represents a compression frame to hold a 1.2 metre masonry panel for dynamic testing. The drawing was used by a number of people including:

1. designer to check for fit and to provide critical geometric information for design of the civil and mechanical systems
2. the electrical designer
3. the builder

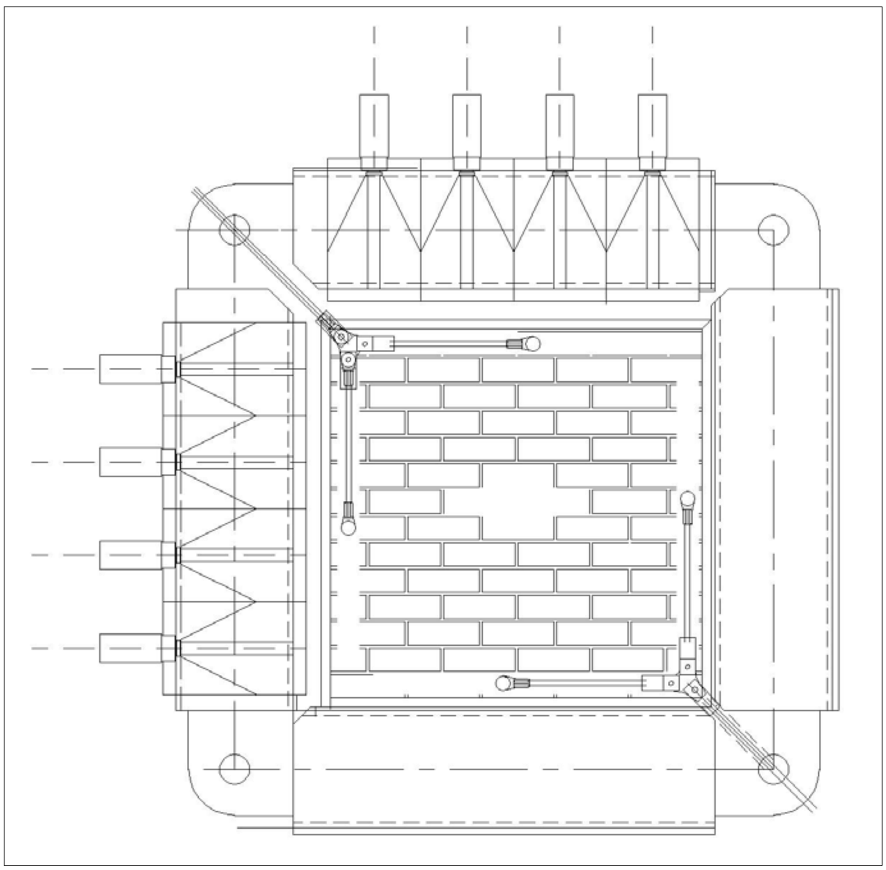

Figure 7. Masonry panel test assemblage

The movement in approach for simple geometric determination to assist building simple Assyrian housing to the complex experimental gear shown in Figure 10 page 23 has taken several millennia. In terms of the current formal mathematics, (Borowski & Borwein, 1989; Kaplan & Lewis, 1971), Figure 6 is a sketch of a straight line in an R^2 space. The figure is a two-dimensional geometrical presentation of a straight line. It constitutes of basic elements defined in terms of standards of geometry. This knowledge of geometry and understanding of Pythagorean theory was required by the Assyrians to develop lengths of the pitched roof rafters (Chandrupatla & Osler, 2004).

This was not a very significant problem when buildings were small, but when buildings increase in size the ability to determine angled distance is economically efficient when compared to hand measurement (Hartford, 2005).

The critical information is:

1. The two axes X axis and Y axis are perpendicular to each other. Perpendicular on orthogonal axis means that projection lengths are unique, minimum and accurate
2. The arrow on each axis denotes that they extend in the infinite space in the respective direction
3. Theoretically, these axes are number lines constituted of using text of real numbers R
4. Hence, the space they encompass is a denoted by the symbol, R^2
5. Each coordinate is represented in an (x, y) format, where x and y can have any real number value

6. The axes intersect at coordinates $x = 0, y = 0$, which is termed the origin
7. Each space has an origin point and all the objects are located in that space with respect to origin point
8. All the numbers on $X \& Y$ axes are located with respect to this origin point.
9. Figure 6 has a grid dividing the R^2 space in squares of 1-unit length sides and are laid in an orthogonal pattern (Borowski & Borwein, 1989)
10. The grid helps in determining the scale of the objects on the plane. They are imaginary and only used as reference lines, they are never a part of the geometric analysis
11. Although each line has *zero line thickness* or in other words, the line is supposed to be infinitesimally thin, to match the basic axioms of geometry (Szecsei, 2007)
12. In Figure 6, the two axes are shown in a heavier line weight as they represent the defining number line, which is primary basis for defining the space R^2.

    The example line drawn in Figure 6 has an equation (1)

$$x + y = 4 \tag{1}$$

Where x is the dependent variable and y is the independent variable, with equation (1) linking the X axes data to the Y axes data. If we have two points that satisfy equation (1) then a length along the line represented by equation (1) can be determined using Pythagoras theorem as shown in equation (2):

$$L^2 = (x_b - x_a)^2 + (y_b - y_a)^2 \tag{2}$$

where L is the length measure. In this representation shown in Figure 6, the line thickness is a representation of the importance of the line in the geometric representation, not in terms of the construction importance as would occur in a drawing standard,(Standards Australia, 1992) .

It is postulated that this information represents the minimum information to define a line $\overrightarrow{AB}$ in R^2 (Szecsei, 2007). Table 1 presents the minimum information to determine the geometrical properties of line: $\overrightarrow{AB}$ in R^2 .

Table 1. List of information required to reproduce the geometric data in figure 6 (P. 17)

Number	Information	Sample Data
1	Origin	$(0,0)$
2	R axis	Reals
3	Y axis	Real numbers = R both positive and negative
4	Grid	For construction purposes
5	Scale	To establish coordinate location on plan
6	Line $\overrightarrow{AB}$	A line in the R^2 space
7	$x+y=4$	A simple line in the plane other forms are: $y=a_0x^0+a_1x^1+...+a_nx^n$ (3) where n is theoretically infinite, but in construction terms usually the limit is $n\leq 2$ (4) Or in more general terms: $y=\sum_{0}^{i=n} a_i x^i$ (5)

It is instructive to look at the modern style as in Autodesk Inc. (2012a) that provided one of the first methods to exchange drawing and geometric data. A sample valid DXF file for a line and a text item is shown in Figure 8.

```
  0
ENDSEC
  0
SECTION
  2
ENTITIES
  0
LINE
999
subroutine draw    3
  8
L10-50
 62
        4
 10
  364917.8440
 20
 1625153.0310
 11
  364988.8270
 21
 1625167.7640
  0
TEXT
999
subroutine DRAW_LINE_Q
  8
FLOWS
 62
        1
 10
  364953.3355
 20
 1625160.3975
 30
0.00
 40
6.50000
  1
  14.0
 50
0.00000
 0
ENDSEC
  0
EOF
```

Figure 8. DXF file format for line and text

The result of application of opening the DXF file with AutoCAD 2011 is shown on Figure 9.

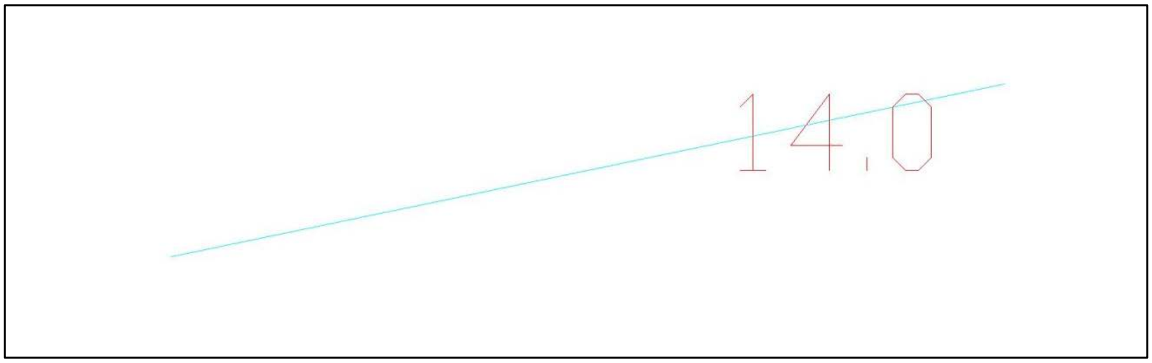

Figure 9. AutoCAD DXF file input result

The simple DXF example shown in the figures presents some of the additional information required for drafting in a computer aided system. A complete reference to this system is in the DXF Manual, which is available online (Autodesk Inc., 2012a).

Vitruvius (Cencelj et al., 2012) provided one of the earliest examples of architectural design. Thus the development of design documents can be traced to the first architectural book by Vitruvius, *De Architectura,* who published ten books on Architecture. These books provide a rather prescriptive technique for design and construction, as would be expected for guild type rules, rather than modern codes of practice based on structural reliability principles (Chan & Melchers, 1993; Melchers, 1987). Vitruvius' book is a written record of one of the oldest architectural documents surviving until today. The work by Vitruvius is one of the most important sources of modern knowledge of Roman building methods as well as the planning and design of structures (Cencelj et al., 2012).

Figure 10. Greek House Plan by Vitruvius (c 30 BC) is an example of a very old construction document containing in drawing terms the minimum information required for the construction plan of the walls. There are significant details missing in terms of construction, but the plan concepts are clearly presented.

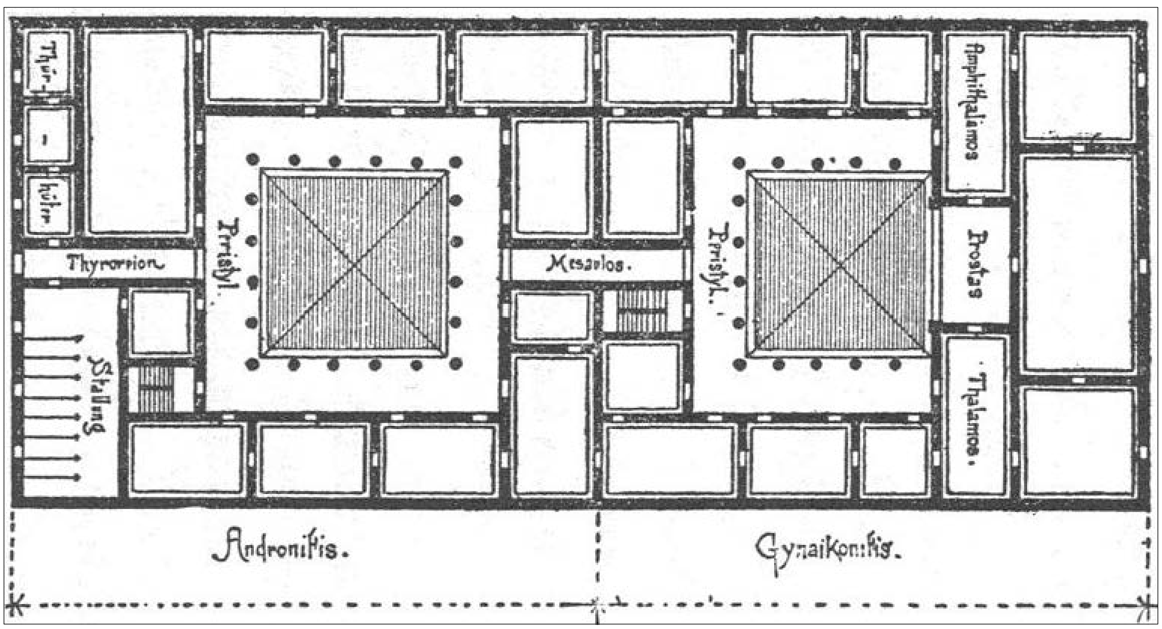

Figure 10. Greek house plan by Vitruvius (c 30 BC)

In a similar analogy, the aim of a good drafting technique is to provide information only once on a set of drawings. The purpose here is to avoid conflicts, although in reality it is hard to achieve in hand drawings. Vitruvius used this design documents to teach architecture to others in the Roman world. This drawing may not be buildable today without extensive research, but the Greek owner would have had the buildings constructed using the type of information shown in this drawing.

It is possible, given tolerable assumptions, to interpret these design documents as containing the minimum information required for the local builders in 15 BC. The local builder had knowledge of local construction, and could understand the building's construction method.

The design plan is a schematic representation; much is as used as in modern drawing preparation. This document is an extension of the knowledge acquired by geometry and provides an example of the use of geometry and its application for presentation purpose.

This drawing constitutes of straight lines intersecting each other at right angles. However, the lines differ in the way they are presented in the drawing as:

1. The walls, sills, the windows, the level changes all represented using lines but the line weight change.
2. Line weight is not in itself important to convey the geometric information, but the line thicknesses are changed for example to differentiate between the cross-section of a wall and top view of steps.
3. The concept remains the same, the line in itself does not have any thickness but it made thick for mere presentation and ease of understanding.
4. Although the builder can execute the work with this drawing but it, still lacks its simple dimensions. The stair and the horse stallion imply the scale in the figure.

Vitruvius' drawing shows the development of an engineering drawing style that remained steady until the early 1960s with the development of the computer aided drafting.

Middle Ages Drafting

Outside the European and Mediterranean traditions, one can look at the large buildings of the Far East to gain an understanding of the change in drawing from the Roman to the Middle Ages, ultimately leading to perspective drawings. Figure 11 shows the Taj Mahal as a front view, as would be drawn to show the look of the building to the owners.

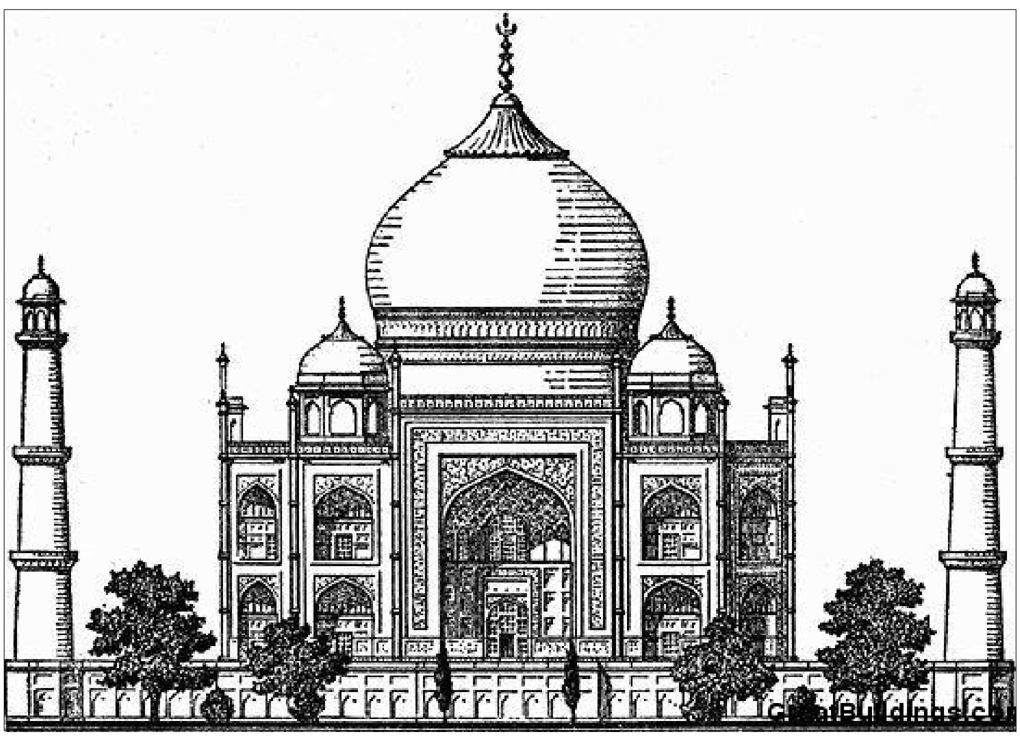

Figure 11. Taj Mahal (built 1632–1653) (ArchitectureWeek, 2001)

In historical terms, the Taj Mahal is a white marble mausoleum built by Mughal Emperor Shah Jahan in about 1600 A.D. The construction of the Taj Mahal was entrusted to a board of architects under imperial supervision, including Abd ul-Karim Ma'mur Khan, Makramat Khan, and Ustad Ahmad Lahauri. Taj Mahal is considered by most as the finest example of Mughal Architecture. The building is an integrated complex of structures in itself, including the domed structure and minarets. It has enormous carvings and intricate details, which perhaps would have made the preparation of its construction document even more laborious. With the complexity of structure, the time of construction was significantly more than an ordinary building, about 21 years, and involved a large work force during construction. ("Taj Mahal," 2011).

The major advance in the Midddle ages was the development of perspecitve drawing as shown in Figure 12.

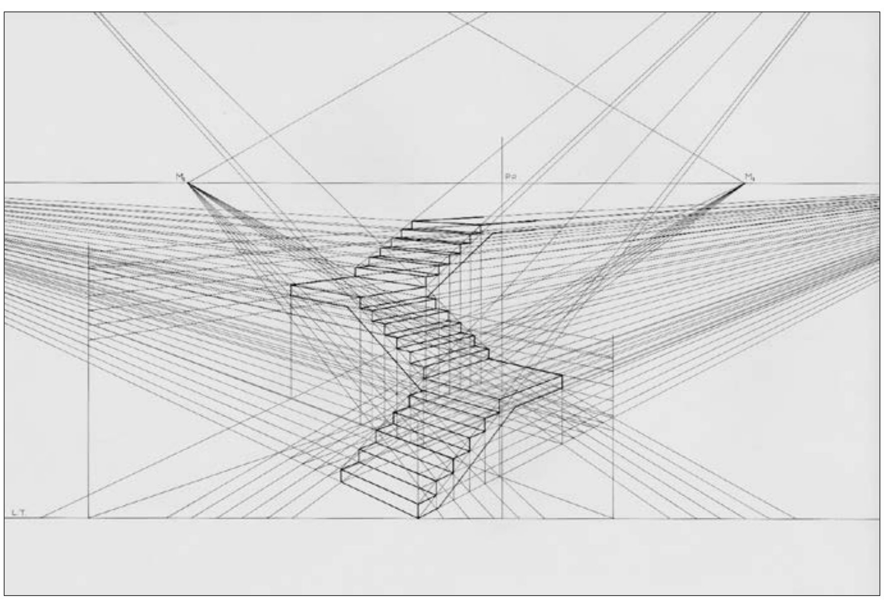

Figure 12. Two point staircase perspective (Testoni, 1995)

Figure 12 shows two point perspective, in this case a staircase. Perpective provides a method for visually entities in three dimensions.

Drafting until 1950

There is no point in time in the middle of the twentieth century where one can say, before this time there was no computer drafting and after this time there was computer aided drafting. A tolerable estimate of the time when the change is recognized by the academic and industrail complex is about 1950 (Winston & Horn, 1989). Computer technology advanced significantly from 1950 till 1965, at IBM and BOEING as examples, as can bee seen in the development of structures programs and computer languges, Lips and FORTRAN being seminal examples.

So starting in the pre-1950 period, whilst steel had been available for millennia, it could not be produced in significant quantities to affect human life in terms of improvement in habitation until the 19th century. The Industrial Revolution of the late 18th and early 19th century witnessed the development of technologies in:

- Cement and concrete (Young, Mindess, Gray, & Bentur, 1998)
- Steel, advanced significantly with the development of munitions in the period after the Civil War (Mott, 1947)
- Cast Iron, although the statistical problems in the safety determination of cast iron elements mitigated its extensive use

Figure 13 shows one of the iconic steel structures from the 19th century, the Eiffel Tower. The change in plan presentation is evident with the construction of Eiffel Tower, and shown on the associated plans.

The work took about twenty eight months The Eiffel Tower structure designed by A. G. Eiffel was erected in the Champ-de-Mars for the Paris exposition of 1889. The tower is 300 metres high and consists of an iron framework supported on four masonry piers, from which rise four columns uniting to form one shaft. Three platforms at different heights can be reached by stairs and elevator (Eiffel, 2011).

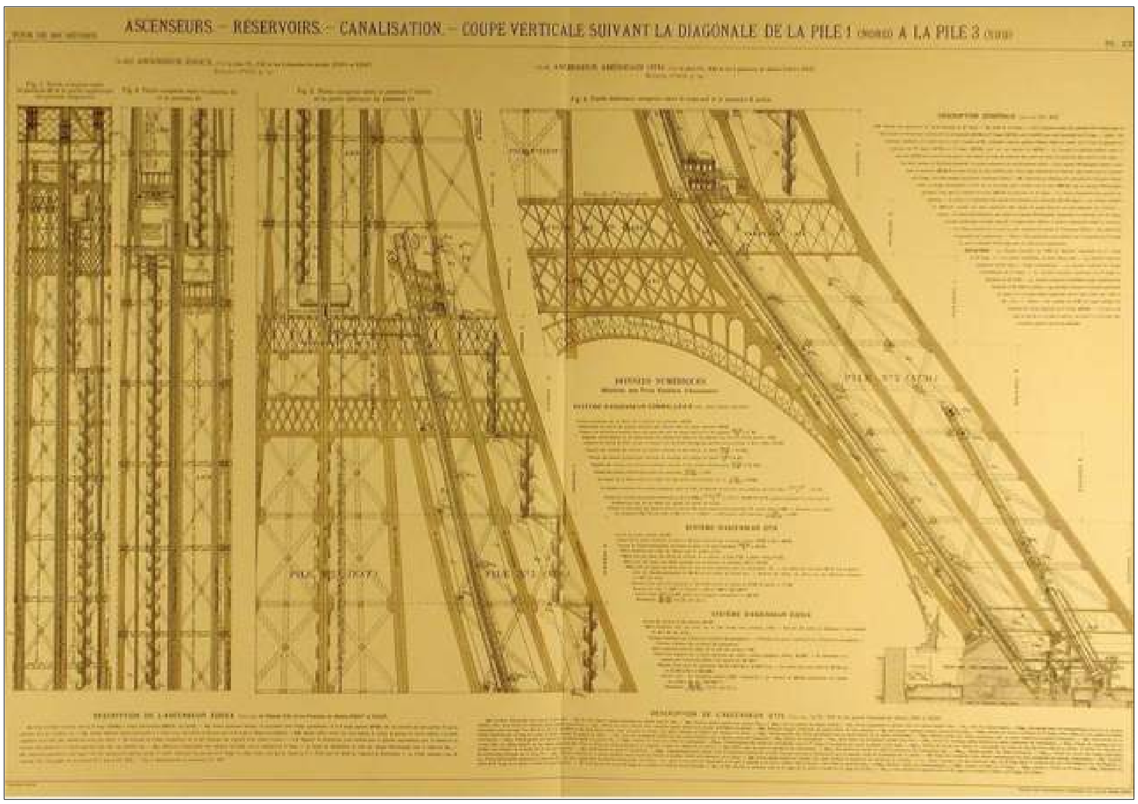

Figure 13. Eiffel Tower blue print (Barcelona, 2010)

The drawings are much more detailed and expressive than those of the Greek house as shown in Figure 10 (page 23).

The critical elements on the drawing are:

1. The line weights are considered, the smallest dimensions are provided.
2. The keynotes are provided over the document for immediate reference. This drawing could be considered as one of the most "complete construction drawing" considering the amount of detailed information provide.
3. By making such detailed drawings a minimum standard for construction documents, the European construction industry was moving towards globalization of architecture.

This dramatic change from the 17th to the 19th century when compared to the relatively slow rate of change up to that time from the period from the Assyrians to the Italian Renaissance also spurred differentiation within the building industry. The responsibilities of the builder were split into the architect, engineer, construction specialists and builders, with the English adding a category termed quantity surveyor. The English Quantity Surveyor has had a significant impact on measurement techniques and standards development (RICS, 2000)

This responsibility change is visible with the rise of the major professional groups, American Society of Engineers founded in 1852, Institution of Civil Engineers founded in 1818, American Institution of Architects founded in 1857 and the Royal Institution of Chartered Surveyors founded in 1868 leading to a period of increasing regulation, ultimately of most concern about human safety (Health and Safety Executive, 2002). The establishment of standards by the International Standards Organization and American National Standards Institute date from the late nineteenth and early twentieth centuries with the early work of Baker (I. O. Baker, 1914a; I.O. Baker, 1914b) setting the format for most standard later developed in the USA, with the American Institute of Steel Construction (AISC) (2005) being a prime example.

Figure 14 shows a sample drawing taken from the Baker textbook. This section shows a dam built in Maine at Ellsworth.

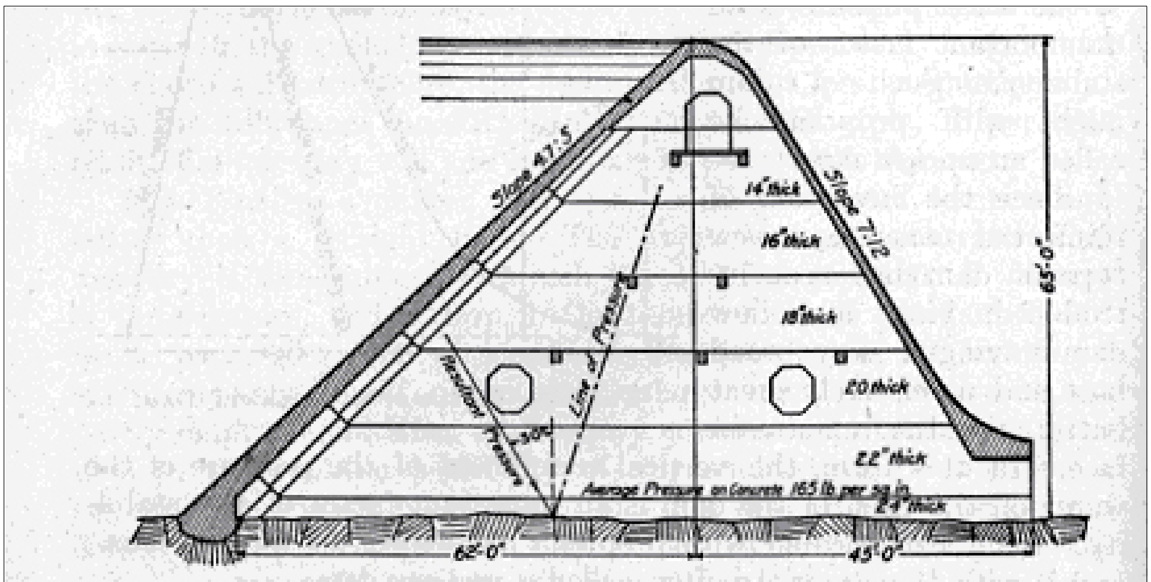

FIG. 106.—ELLSWORTH (MAINE) HOLLOW DAM.

Figure 14. Baker text - sample drawing (after I. O. Baker (1914))

DEVELOPMENT OF COMPUTERS

The development of the computer during the World War II was pushed by the need to solve ballistic type problems. The Boeing Corporation pioneered the use of matrix inversion technique to solve Finite Element model problems for the design of planes and missiles. This military use has been displaced by the private industrial use of computer technology (Winston & Horn, 1989).

COMPUTER AIDED DESIGN IN CONSTRUCTION

Figure 15 shows a modern house plan completed by HandtoCAD a small company in Raleigh, NC that takes hand drawn plans and completes a digital copy. The point to take from this figure is not that a computer aided plan can be easily created, it does not require any knowledge other than drawing skills. HandtoCAD will convert any form of drawing as long as originals or raster files are available (HandtoCAD, 2012).

In the last six decades, the methods used to produce design documents have changed from hand drawings to electronic 2D drawings and then onto #3D drawings.

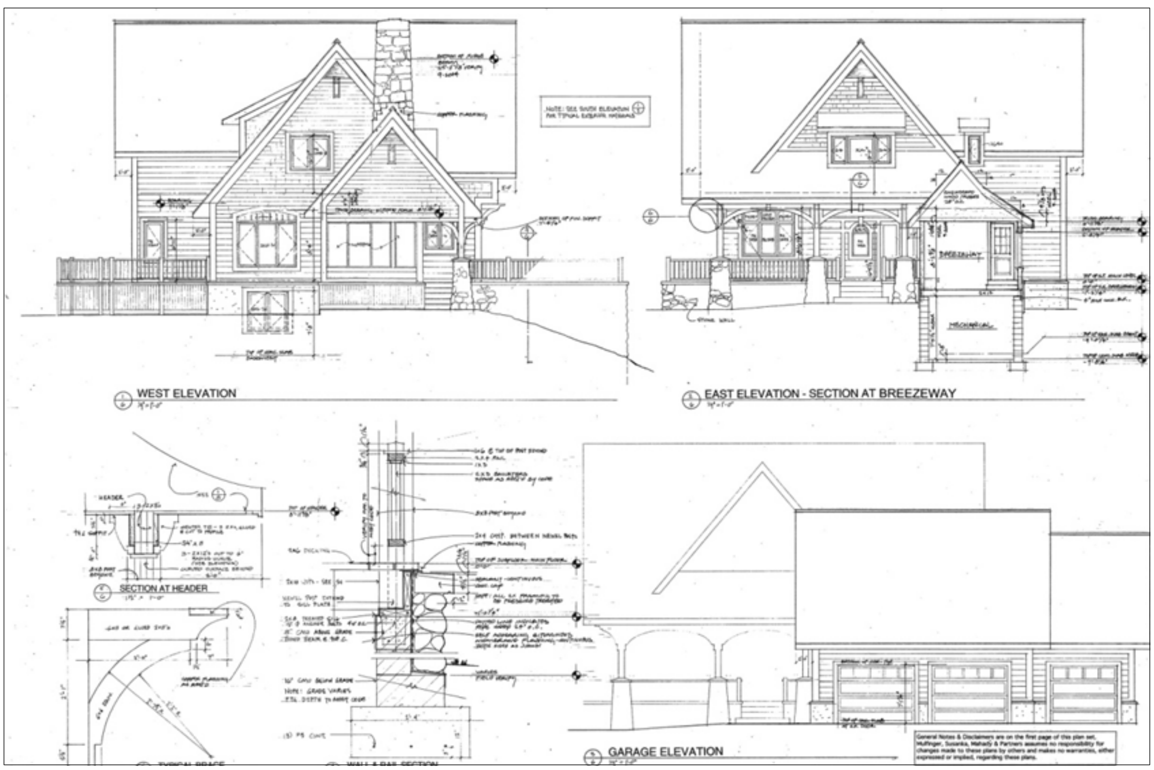

Figure 15. AutoCAD drawing of the elevation of a house (HandtoCAD, 2008)

This drawing contains:

1. a variety of line thicknesses to provide contrast in the drawing as with hand drawn plans
2. elevation details to allow an expert to understand construction
3. construction details at critical points

With the advancement and globalization of technology, the minimum building information contained in the document has become more complex (Veshosky, 1993). The number of documents in set of construction drawings has typically increased. This in turn has increased the need of automation in production of construction documents (J.M. Nichols, 1989; J. M. Nichols, 2011) as is seen in the development by Nichols of Sewer Design Programs in the late 1980s to meet a need for rapid production of long lengths of sewer for existing urban areas.

The productivity benefit of not having to redraw a plan if a change was made and the ability to insert 'ready drawn' industry symbols provided a compelling business advantage (Christy Oommen, 2010). AutoCAD has become the dominant world player. Autodesk manufactured AutoCAD, and then slowly absorbed Navisworks, Revit and Robot to provide a suite of programs that provide significant design and drafting ability beyond that available in AutoCAD. The clear objective is to produce unambiguous contract documents, allowing for normal economic advantages taken by the writer of the document.

MERITS OF CAD FOR PRODUCING CONSTRUCTION DRAWINGS

Early CAD software between 1970 and 1980, provided users with a list of vectors (lines, circles and arcs), which were stored in a file. As time and technology progressed, these lines, arcs and circles were able to be segregated in many different ways - e.g. blocks for quick insertion of repetitive groups of lines. CAD program developers then added the ability to extend the data related to these entities and provided a chance to store more pertinent information in the database and manipulate the data using some form of computer language, such as AutoLISP (J.M. Nichols, 1989) .

Software like Autodesk Revit furnishes real-world objects (or classes) which are controlled by a small sub-program. They hold behavioral intelligence to each instance (occurrence) of that object (door, wall, window etc.) in the drawing. This is a major advance from the use of a drawing to merely represent, to the ability to model and analyze with intelligent feedback (Christy Oommen, 2010a).

Figure 16 shows a figure from the paper by C. Oommen (2010a) on the transition from the drawing board to integrated project delivery methods.

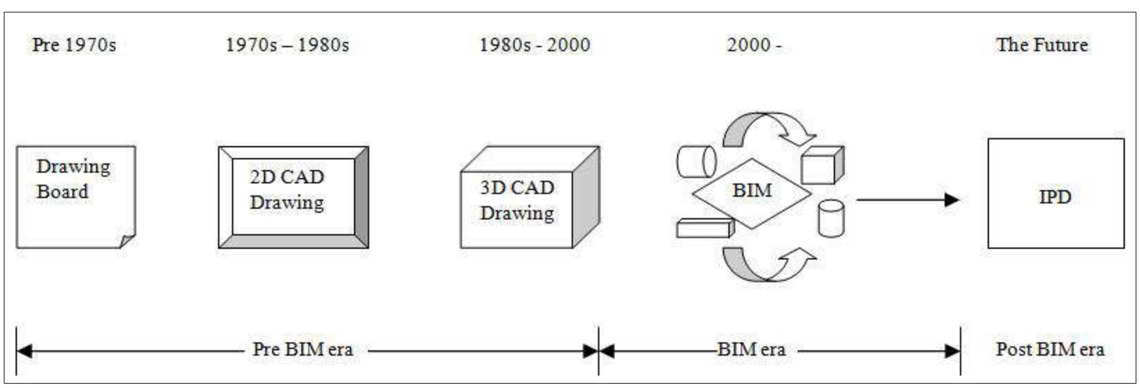

Figure 16. Transition in design development mediums (after C. Oommen (2010b))

Two dimensional drafting was replaced with three dimensional modeling systems that represent the objects making up a building. Parametric three dimensional modeling is an advanced application that incorporates the objects and their respective relations in different disciplines within the construction industry.

Building Information Modeling (BIM) provides a wealth of information on design, potential conflicts and building methods from the ability to visualize the data for a building (Björk & Laakso, 2010; Holness, 2006; Klemens, 1999).

BIM is an approach for designing buildings and managing construction tasks across multidisciplinary fields. It contributes in generating and managing building data during building's life cycle facilitated by design software. It provides a different approach to design and construction processes as it can change the sequence of activities and responsibilities of the parties involved at each stage. It can provide the imperative information like materials, schedule, and estimates of the facility. (Ward, 2009).

Figure 17 shows a proposal in BIM for the world's tallest building.

Figure 17. Conceptual BIM view of Burj Khalifa (Arab News, 2012)

The transformation in presentation technology is progressive, this will continue to develop and attempting to determine where it will be in twenty years is hard.

EARLY METHODS

Nichols (1989) developed a program that would design sewers using a three dimensional survey data set. The issue that were present in1989 and identified by Nichols were:

1. Pre lining design was by hand for the sewer layout because of the relative geometric complexity of urban development and the issue of typology of the land mass.
2. Design rules were complex and really designed for hand analysis rather than a computer based approach.
3. Conflict resolution with other services is the key issue, both is finding the objective and is getting their issue location is X,Y,Z terms. It is very easy to make a mistake in this data collection phase.
4. Design could produce drawings that were buildable but not human readable

The key issue was 'conflicts' between the existing and the planned work.

BUILDING INFORMATION MODELS

Background

There is a gradual knowledge and building standard change that should be leading to contract document improvements. The goal of contract documents is to transfer approximately agreed matters into design information that can be included in construction contract documents. The question is raised as to whether:

> *Can this be an entirely numerical process, moving away from the use of drawings as the contract media?*

Building Information Modeling (BIM)

The National Building Information Model Standard defines Building Information Modeling as, "…a digital representation of physical and functional characteristics of a facility" (Madsen, 2008) They also state that it is intended to be a shared knowledge resource about a facility, and that it is a basis for decision making throughout the project(Klemens, 1999).

Architects and engineers benefit from using this technology because it allows their clients to get a better understanding of the building, by using three dimensional models and clear drawings. The main goal of BIM is to provide better communication among the parties involved in a project. “BIM facilitates better communication and accuracy, reduces ambiguity, increases efficiency, and reduces work” (C. Oommen, 2010a).

BIM is a paradigm shift from traditional drafting and design and is sometimes wrongly referred to as a product. BIM is an ecosystem of technology, processes and policies and is a set of interacting policies, processes and technologies generating a methodology to manage the essential building design and project data in digital format throughout the building's life-cycle (C. Oommen, 2010a). Figure 18 shows this definition.

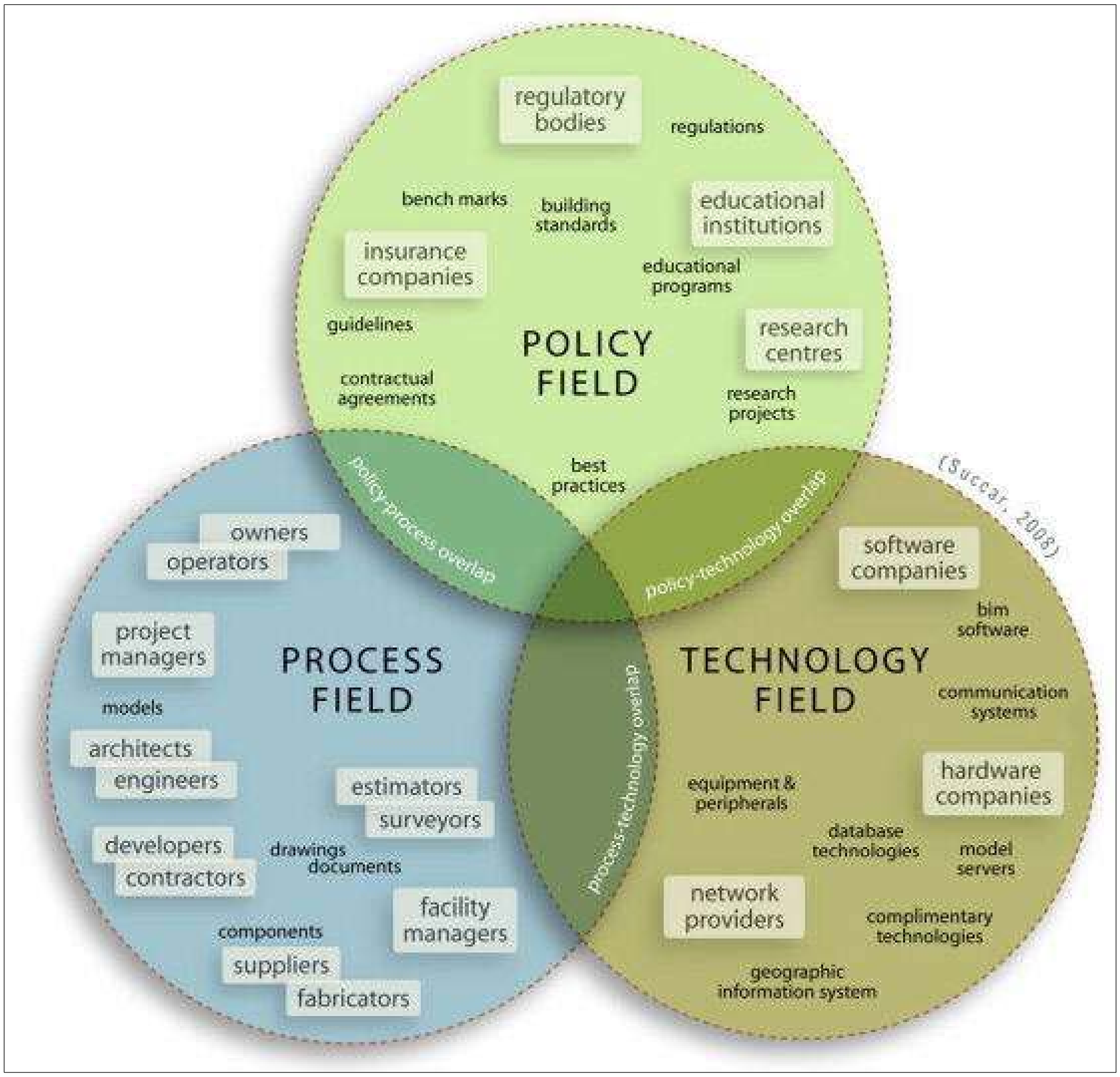

Figure 18. Three interlocking fields of BIM activity – Venn diagram (C. Oommen (2010b))

The AIA in conjunction with its Integrated Practice Conference released in 2007 the first draft of its working definition of an IPD Model. One of the essential principles of the IPD is open and interoperable data exchanges based on a disciplined and transparent data structure which is essential to support an Integrated Project Delivery.

The IPD working definition document defines BIM as a digital representation of physical and functional characteristics of a facility. BIM is a shared digital representation founded on open standards for interoperability, (Grilo & Jardim-Goncalves, 2010). Figure 19 demonstrates the principles articulated by the AIA.

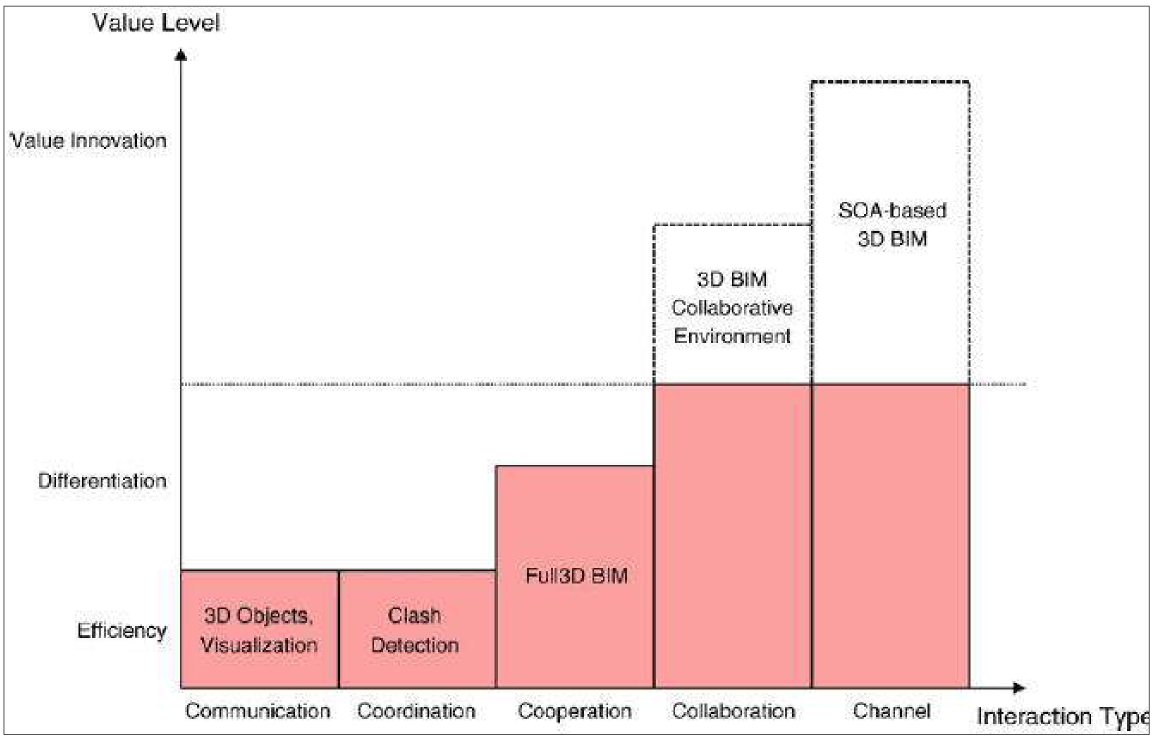

Figure 19. Value level of interoperability of BIM (Grilo and Jardim-Goncalves (2010))

Industry Review of BIM software

According to the 2006 AIA Firm Survey, 16% of AIA member-owned architecture firms used BIM technology and 64% of the firms used BIM for billable work (Riskus, 2007). BIM allows most of the basic building information that is put into the models to be run through this type of analyses. For example, all of the information used in the traditional process like doors, windows, and walls can be modeled in a BIM program (Tardif, 2007).

Many companies have invested in producing software that support the of BIM tools, because of the fiercely competitive nature of the design market. A list of some of the most popular BIM software used in construction industry follows:

1. Revit Series:
    a. Revit Architecture (Autodesk Inc., 2011a)
    b. Revit MEP (Autodesk Inc., 2011b)
    c. Revit Structure (Autodesk Inc., 2011c)
2. ArchiCAD (Graphicsoft SE., 2012)
3. Vico Constructor, Vico Software Inc. ("Vico Constructor," 2012)
4. Bentley Architecture, Bentley Structure: Bentley Systems Incorporated (2012b)
5. Vectorworks Architecture: Nemetschek Vectorworks, Inc. (Vectorworks, 2012)
6. Tekla, Tekla Structures: Trimble Company (2012)
7. Navisworks Manage: Autodesk Inc. (2012b)

Each software package has a different interface and produces BIM drawings in a specific format for each package. Each integrated model contains a vast amount of project information like material quantities and design. The question arises, how to allow seamless information exchange *with minimal cost and no data loss* between different components of a work being executed using BIM. This is a major issue that concerns software and hardware vendors, standards developers, and customers (Zhao, Xu, Kramer, Proctor, & Horst, 2011). Hence, there is a need to standardize a database where all the software can share the same information and visually represent the data in a consistent format. One method is the use of a XML format that is easily extensible.

XML

XML was originally designed to meet the challenges of large-scale electronic publishing. Its roots stretch back to well before the Internet existed. XML is a descendant of the "markup" process used by editors prior to the days of automated typesetting. An editor would write specific processing instructions on a document to delineate its organization and presentation style. A typesetter would use the markup to set the type in the manner appropriate for conveying the editor's vision to the reader. The markup process was retained but adapted when automation and typesetting converged. Markup was now included with the machine-readable document but the specific processing instructions were written in the language of the formatting program rather than the language of the typesetter (Begley, Palmer, & Reed, 2005; Begley & Sturrock, 2000).

While computerized typesetting represented a major advance, it also introduced a new problem: markup instructions differed on different typesetting systems. A file containing the marked up document could not be readily used on another automated typesetting system without revising the markup. The solution to this problem came in step-wise fashion from the development of generic coding to the SGML(Begley et al., 2005; Begley & Sturrock, 2000). XML is a simple, very flexible text format derived from SGML. XML brings the three principal features of SGML to the Web:

1. Extensibility: users can define their own tags and attributes used in their documents;
2. Structure: users can define their own document schema, which is the information model of a document describing how the tags and attributes are combined;
3. Validation: users can test the conformance of their documents to the structure defined by the schema.

Additionally, XML intentionally does not include some of the complex functionality of SGML. It was designed to be easy to learn, easy to write, easy to interpret, and easy to implement; characteristics perfectly suited for use on the Web (Begley & Sturrock, 2000).

This description of XML emphasizes its role in the world of structured documents. XML also offers the possibility of creating program independent data exchange formats. The syntactic rules for constructing an exchange file through the markup of instance data are:

- simple
- well documented
- widely supported in commonly available software tools
- resulting text-based file format is easy to parse.

In any given exchange scenario, users achieve interoperability by agreeing to restrict their XML documents to some specific set of tags. These tag sets are known as XML applications (Begley et al., 2005).

Figure 20 provides a sample XML format, in this case the employee sample file from the Microsoft 2007 XML Notepad program.

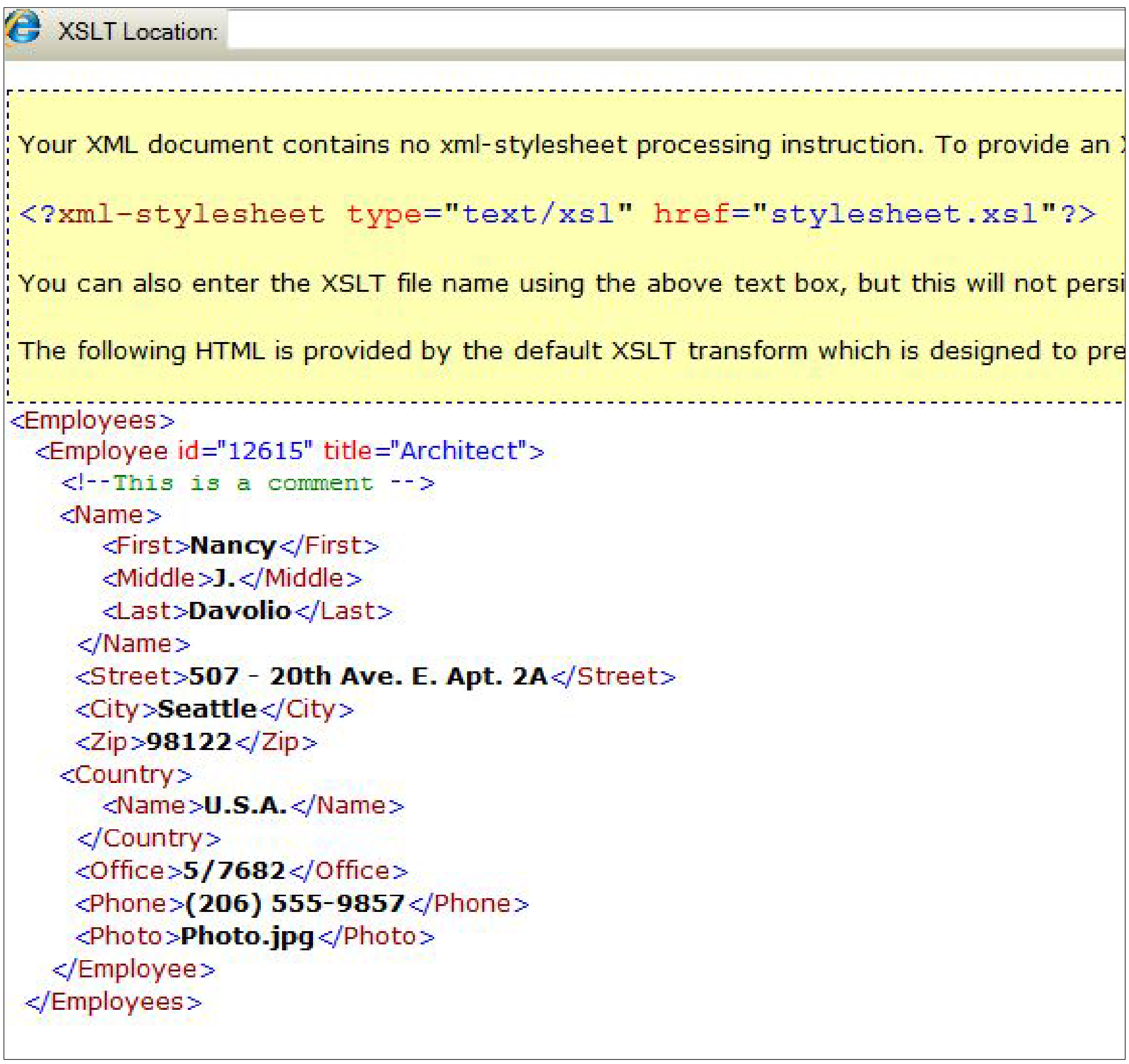

Figure 20. XML sample

Industry Foundation Classes XML

Industry Foundation Classes provide a data model for use in exchanging data on buildings and other construction activities. In recognition of the impact of XML in other IT domains, the fifth and sixth releases of the IFC have also included XML schema definition language representations, which are known as ifcXML1 and ifcXML2, respectively. The goal of this work was to make it possible to exchange IFC data files alternatively as XML documents. Another, equally important goal was to enable the reuse of IFC content and structure within XML-based initiatives for data exchange and sharing in the AEC/FM industries (Grilo & Jardim-Goncalves, 2010; Nisbet & Liebich, 2007).

Some progress has been made to create object definition standards for the transfer of these AEC object models but there is an enormous task in hand if all the current volume of AEC objects is to be translated through IFC. The IFC file format for transfer of complete building information models has endured one of the most lengthy standardization processes within construction (Howard & Björk, 2008).

SUMMARY

In the end the purpose of drawings is to provide a picture for the person constructing an object. This literature review has outlined the progress from the Assyrian geometry to the modern implementations of BIM. The problem is the interchange of data between the various programs without loss of information. This is a significant challenge that will be solved, but not before further significant work on exchanging geometry and other properties of buildings.

CHAPTER III

METHODOLOGY

INTRODUCTION

The experimental work is based on the use of a series of drawings and a XML file to build a set of concrete beams. Methodology is divided in to three sections:

- Preparation of drawings
- IRB approval
- Selection of the Participants

PREPARATION OF DRAWINGS

Background

The first step was preparation of construction drawings of the beam. The four chosen participants were provided with the drawings in four different forms – hand drawing, Auto CAD drawing, Revit drawing and XML file. Logically, the beam produced by using any of these mediums would follow same steps of construction and the final output would be the same.

The aim of this section of the study was to observe if the constructed beam differ, depending upon the medium of preparation of drawings and if the participants need additional information for construction of their beam. The review comments need to consider whether the information contained in these drawings is absolute for construction.

Hand Drawing

The simplest drawing in terms of manufacture is a hand drawn sketch of the proposed beam. This sketch has to show the beam dimensions, a plan and an elevation. The beam dimensions are 912 mm long, 150 mm high and 100 mm breadth.

Figure 21 shows the hand drawn sketch.

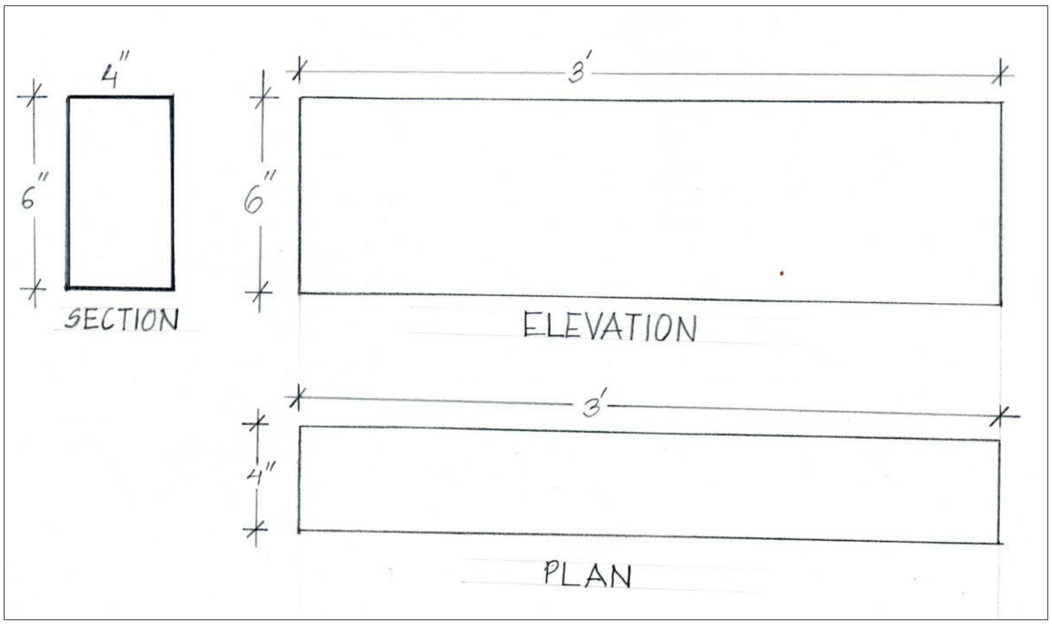

Figure 21. Beam - hand drawn

AutoCAD Drawing

The AutoCAD drawing represents the step from hand drawing to the lowest elements of computer aided drafting. Figure 22 shows the AutoCAD Drawing for the concrete beam. This drawing shows an increased level of information including the formwork and notes for construction. There is of course no reason the information presented on the first two drawings was not identical.

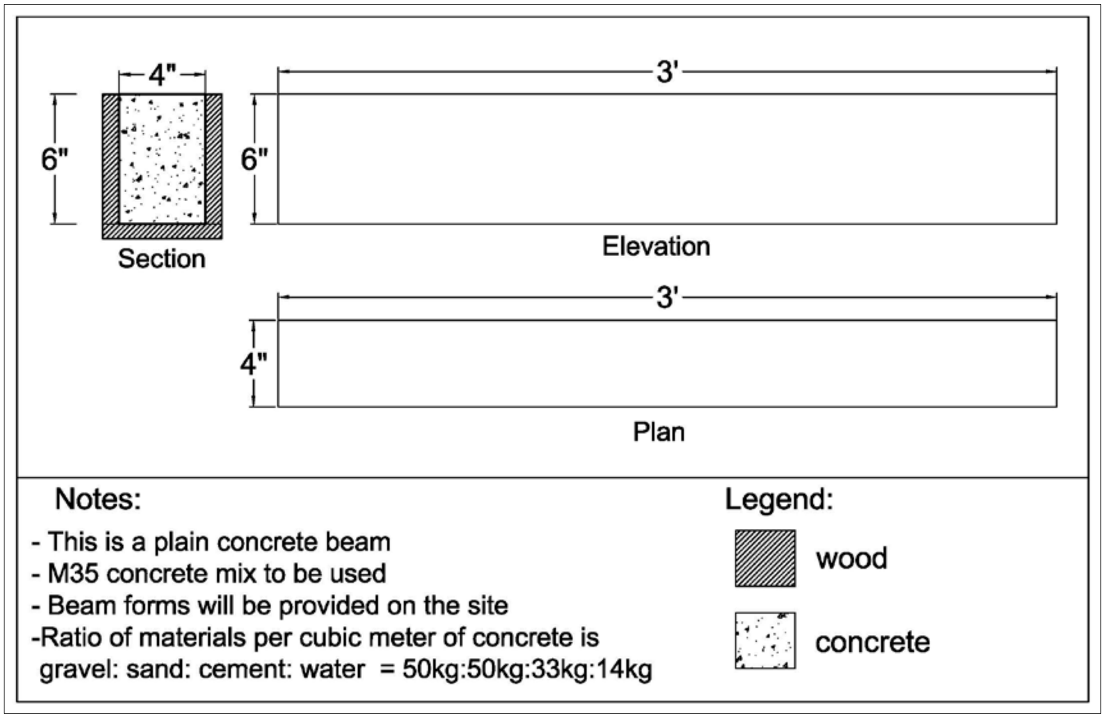

Figure 22. Beam AutoCAD drawing

REVIT Drawing

The REVIT drawing represents the step from an AutoCAD Drawing to the step of entry to BIM. Figure 23 shows the REVIT Drawing for the concrete beam. This drawing shows an increased level of information including the formwork and notes for construction, a rendering but not the formwork. There is of course no reason the information presented on the three drawings was not identical.

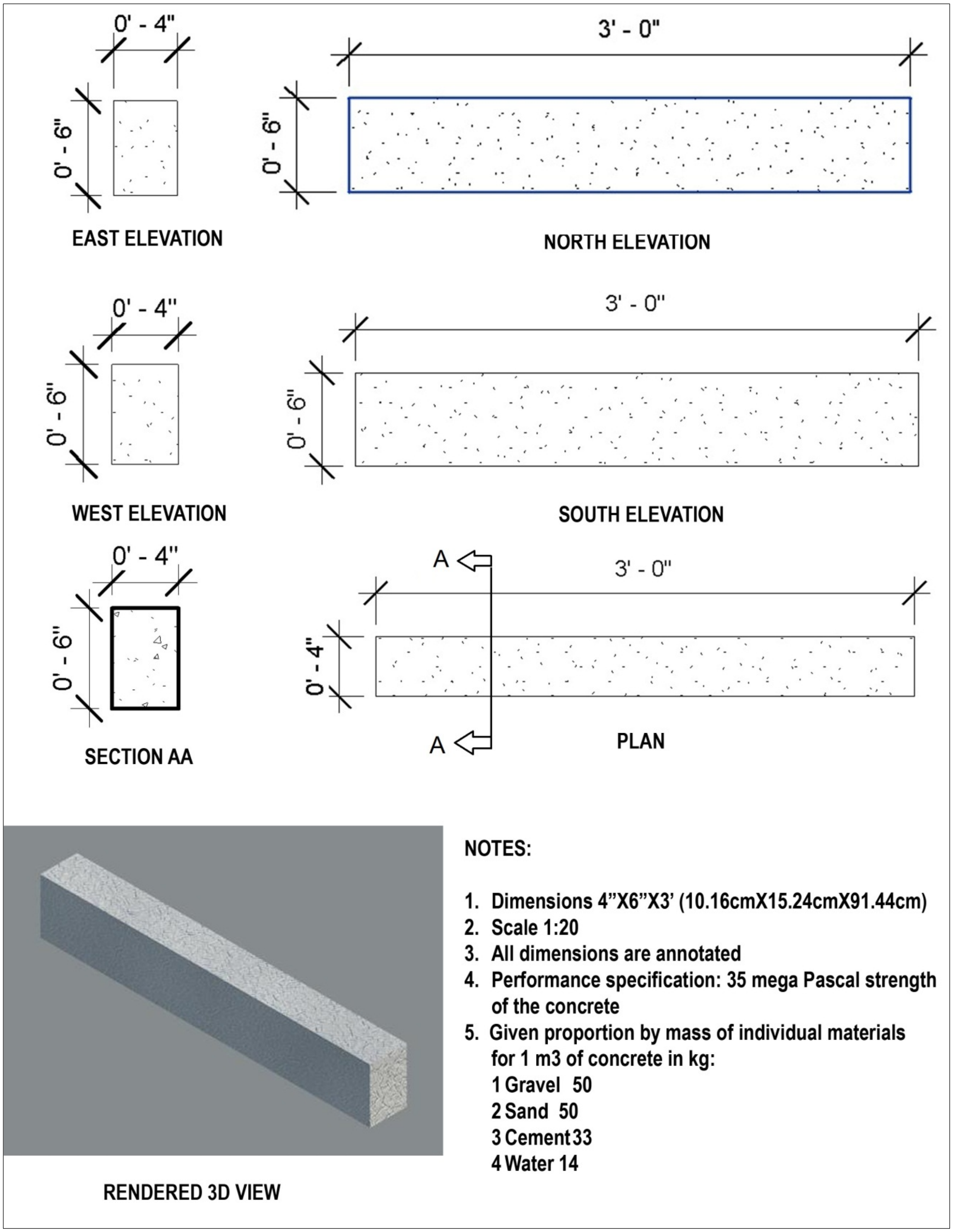

Figure 23. Beam Revit drawing

Notes

The information provided in the form of builder's notes is presented in Table 2

Table 2. Information in the construction drawings

Item	Description	Unit
1	Length	914 mm
2	Breadth	102 mm
3	Depth	152 mm
4	Scale	1:20
5	All dimensions were annotated	note
6	Concrete	35 MPa
7	Wooden forms to be provided on site	note

Table 3 provides the proportion of materials to be used in the concrete. This information was requested by the builders.

Table 3. Proportion by mass of concrete materials

Item.	Material	Quantity (kg)
1	Gravel	50
2	Sand	50
3	Cement	33
4	Water	14

XML File

The drawings and notes presented in this chapter provide the necessary information to create an XML File for documenting the beam construction. The file format and data is shown in Table 4 and Table 5.

Table 4. XML format and data concrete beam

XML File Format for Concrete Beam

```
<Beams xmlns="http://Concrete">
  <Beam id="1" type="Plain">
    <!--This is a simple plain beam used for demonstration purposes-->
    <Dimensions>
                  <First>900</First>
                  <Second>150</Second>
                  <Third>100</Third>
    </Dimensions>
                  <CoordinateSystem>
                    <Form>XYZ</Form>
                    <Units>millimetres</Units>
                    <Origin>(0,0,0)</Origin>
                    <X>First</X>
                    <Y>Second</Y>
                    <Z>Third</Z>
                  </CoordinateSystem>
                  <Materials>
                    <PC>
                              <Strength>35</Strength>
                              <Units>MPa</Units>
                              <Test>28 Days</Test>
                              <Standard>AS 3700</Standard>
                              <DefaultMix>
                                                  <Massunit>kg</Massunit>
                                                  <Sizeunit>mm</Sizeunit>
                                                  <FineAggregate>
                                                  <Mass>50</Mass>
                                                  <maxSize>2</maxSize>
                                                  </FineAggregate>
                                                  <CoarseAggregate>
                                                  <Mass>50</Mass>
                                                  <maxSize>20</maxSize>
                                                  </CoarseAggregate>
                                                  <Water>
                                                  <Type>Potable</Type>
                                                  <Mass>14</Mass>
                                                  </Water>
```

Table 5. XML format and data concrete beam continued

XML File Format for Concrete Beam Continued


```
                                                <Cement>
                                                <type>I</type>
                                                <Mass>33</Mass>
                                                </Cement>
                              </DefaultMix>
                    </PC>
                    <Formwork>
                              <type>Plywood</type>
                              <Thickness>12</Thickness>
                              <units>mm</units>
                    </Formwork>
                    <Finish>Trowelled</Finish>
                  </Materials>
    <Designer>JMN</Designer>
                    <Date>
                      <Design>
                              <Year>2012</Year>
                              <Month>1</Month>
                              <Day>26</Day>
                              <Completed>T</Completed>
                    </Design>
                    <Built>
                              <Year>0</Year>
                              <Month>0</Month>
                              <Day>0</Day>
                              <completed>F</completed>
                    </Built>
                    <Inspected>
                              <Year>0</Year>
                              <Month>0</Month>
                              <Day>0</Day>
                              <completed>F</completed>
                    </Inspected>
                  </Date>
<City>College Station</City>
<Zip>77843</Zip>
<Country>
<Name>U.S.A.</Name>
</Country>
</Beam>
</Beams>
```


The tables maintain the indentation implicit to XML File presentation.

IRB APPROVAL

The second step followed was obtaining the Institutional Review Board (IRB) approval. Obtaining the IRB approval was necessary as human subjects were involved during the course of the study. It took about 40 days for approval after the application was submitted. After the application was received by the IRB, the IRB requested further information and corrections as is fully listed in Table 6.

Table 6. IRB application and approval

Location	Comment
APPENDIX A	IRB approval
APPENDIX B	Sample email # 1. Request for Participation:
APPENDIX C	Sample email # 2. Response to approval for participation:
APPENDIX D	Consent Form:
APPENDIX E	Form of Conflict of Interest

SELECTION OF THE PARTICIPANTS

Four graduate students of Construction Science Department, College of Architecture were selected to be the participants of the study. For selection, all the graduate students were approached via email with a request to participate in the study, in accordance with the IRB Approval.

The participants who sent their consent to participate in the study were then sent:

1. Response to approval to participate in the research study – "BIM – Minimum Mathematical Configuration"
2. Consent Form
3. Drawings and Notes

In the first meeting with the participants, the researcher explained the task they required to perform for the study. To build the beam all the necessary equipment were provided including:

1. materials: water, cement, fine sand and coarse gravel
2. tools: trowel, shovel, gloves, eye gear, concrete mixer
3. pre delivered wooden molds, empty buckets, weighing scale, trolley
4. stationery for calculations

Methods used to document the results were:

1. a digital camera to record pictures of the work
2. log of questions asked by the participants to determine the information
3. observation notes by the researcher as the work was completed

COMMENT

It was expected that the participants would be able to construct a plain concrete beam using these notes and drawings, given that they are in a Construction Science program. This assumption proved to be false. In the results section the additional information required to be given to the participants to complete the task is summarized as this data is considered to be a result of the study and not a method.

CHAPTER IV

RESULTS

INTRODUCTION

This section of the research paper presents the results of study conducted to document the construction of a plain concrete beam at the Architectural Ranch located in the River Side Campus of Texas A&M University, College Station. The study was conducted on twenty-eighth of March 2012 starting at around nine am at the Architectural Ranch. The fourth XML based beam was made on the seventh of April 2012. The study was supervised by the primary researcher and Mr. C. Tedrick, the Ranch manager. The results section includes:

- Instructions provided at the Ranch
- Observations
- Experimental Work Comments

INSTRUCTIONS PROVIDED AT THE RANCH

The instructions to the participants were:

- wear toe covered shoes, full pants and eye gear
- a brief tour of the workshop was given, so the participants had an idea of the location of the tools, materials and other resources required for the study
- the procedure to operate the concrete mixer. Mr. Tedrick mentioned specifically:

- to mix the dry mortar first in the concrete mixer and then add water to avoid drying up of concrete in the mixer.
- orient the mixer in a direction against to the wind to avoid the dirt to get into operator's eyes or nose while pouring the dry cement and gravels through the opening of the mixer.

Then, the participants were provided with the drawings, required equipment and the procedure for building the beam was explained and then the participants started the task of building beams.

OBSERVATIONS

Formwork

The wooden forms for the beams were prefabricated at the Ranch by Mr. Tedrick. The dimensions of the finished molds were different from the dimensions provided in the actual drawings. The molds had same cross-sectional dimensions but the length of the mold was about half of the length of the beam in the drawing, 40.6cm, refer to Figure 24. This was the first method change in the study.

Concrete

As the mix of the concrete was same for all the sample beams produced, the first three participants decided to do the weight calculations of the materials together. To begin with this task, the participants attempted to calculate the volume of the provided molds and thereby calculate the mass of the concrete required. The level of information participants had at this step in the study included the provided molds, drawings and the strength specifications of concrete.

Figure 24. Study forms

The participants proceeded by determining the internal lengths of the sides of the mold.

Table 7 contains the measurement of the mold taken by the participants.

Table 7. Volume calculation for the prefabricated wooden mold

No.	Quantity	Measurement (cm)	Volume (cm^3)
1	Length	40.6	
2	Width	10.3	
3	Height	15.5	
4	Volume		6481.79

The participant errors for this task are:

1. no standard errors given for the measurements, one must assume the error as ± 0.5 mm (Squires, 2001), which is improbable to say the least
2. working in nonstandard SI, in this case centimetres, which is understandable but problematic in terms of results
3. implicit error in volume of 0.005 cm^3 which is improbable to say the least

The participant's calculations for the mass of the concrete required for each form is presented Table 8.

Table 8. First set of calculations of mass of individual materials

No.	Material	Quantity (kg)	Volume (m^3)	Factor	Calculated Mass ($kg.m^3$)
1	Gravel	50	0.0064	4	1.28
2	Sand	50	0.0064	4	1.28
3	Cement	33	0.0064	4	0.84
4	Water	14	0.0064	4	0.35

The participant errors for this task are:

1. no questions were asked as to whether the nominal mix design would meet a 35 MPa standard, actually not likely for a characteristic strength, but likely for a mean strength
2. did not ask for the density of the concrete resulting from the supplied mix
3. factor of 4 has no basis in fact
4. The participant calculated mass, N , is given by equation

$$N = 4MV \tag{6}$$

Where N is the required mass in (kg.m^3), an error, M is the design mass (kg) and V (m^3) is the volume of the box. This is clearly in error.

The participants then attempted to start the concrete mixer shown in Figure 25.

Figure 25. Petrol powered concrete mixer

The participants from the above calculations then weighed the individual materials – coarse gravel, sand, cement and water. They were confused after looking at the apparent quantities of the weighed materials and rechecked the calculations. They again ignored the strange units and continued onto mix the material.

After taking all the measured dry materials to the mixer, the participants carefully poured the dry mortar into the mixer and tried to start the concrete mixer. The concrete mixer was a regular petrol powered concrete mixer. After pulling the cord several times, they were unable to start the mixer. After few failed attempts, they approached Mr. Tedrick and he started the machine for them. What they were missing was to switch on the motor.

The participants let the dry materials mix for about 45 seconds and then added water. They let the mixer run for another minute and poured the material in a clean dry bucket to cast it into the molds. The participant in looking at the quantity of the finished material the participants realized their mistake in calculating the mass of the required materials. It was not an error in the numerals but a mathematical error while equating the quantities. They were missing the factor of density during the mass calculations and used the wrong equation.

The participants asked me to specify the density of the concrete, which was given 2400kg/m^3 or 2.4g/cm^3. The point to note here was to calculate individual masses by first determining total mass of concrete required for the given volume and then calculating the individual masses of the materials. This changed their previous set of calculations of mass of individual materials. They also realized that since the calculations could be done in grams and centimeters they could follow these metric units rather than equating centimeters and kilograms and complicating the calculations.

Table 9 summarizes the required mass for each mold in grams.

Table 9. Total mass of concrete required for the study

Density of concrete (g/ cm^3)	Volume/mold (cm^3)	Factor	Total mass (g)
2.4	6481	4	62218

To calculate the mass of each material the participants factored the ratio of weight by proportions with the total mass of the concrete calculated in the table above with the result given in Table 10.

Table 10. Second corrected set of mass calculations for individual materials

No.	Material	Weight by proportions	Total mass (kg)	Quantity (kg)
1	Gravel	50/147	62.218	21.16
2	Sand	50/147	62.218	21.16
3	Cement	33/147	62.218	13.96
4	Water	14/147	62.218	5.92

The masses mentioned above if reported in pounds come very close to the data presented in Table 11. The issue of change of units introduces another potential source of error and given the background of the participants this change is inexplicable and inexcusable (Barbrow & Judson, 1976). There appears to be no reason to switch between units, the scale could be converted to any of the systems used and the proportions given were in kilograms, which is a legal measure in the United States. The ethical issues of change of units in experimental work are not insignificant (Squires, 2001).

Table 11. Proportion by mass of individual materials

No.	Material	Quantity (lb.)
1	Gravel	50
2	Sand	50
3	Cement	33
4	Water	14

The dry ingredients are shown in Figure 26. All ingredients were obtained from a local supply yard. The beam in the left rear side of this photograph is from other experimental work and is not related to this study.

Figure 26. Dry mortar - cement sand and aggregate

The participants, as shown in Figure 27, prepared the wet concrete by:

Figure 27. Participants weighing the materials

1. Weighing the materials individually in a bucket:
    a. Gravel mass: 50 lb.
    b. Sand mass 50 lb.
    c. Cement mass 33 lb.
    d. Water mass 14 lb.
2. Added the dry mortar to the concrete mixer and ran it for about a minute
3. Then added weighed water and let it run for another minute
4. Poured the concrete into the wheel barrow

5. One of the participants asked to perform the slump test. Since the workability of the concrete for the calculated weights was tried and tested, the participant was asked to omit this step from the course of execution.
6. With the help of trowels the participants filled the beam molds.
7. After filling about 2 inch layer of concrete the participants compacted the concrete by using wooden rods and lightly banging the molds to the ground surface, as shown in Figure 28
8. One of the participants accidentally broke the base of a mold while banging it for concrete compaction. With the instructions provided, the participant stopped moving the mold and checked for any lost concrete. Then the student continued compaction by probing the concrete with a wooden rod and after leveling the concrete, slid the mold to the drying/setting area.
9. After filling the concrete till the surface of the mold and compaction, participants leveled the surface by the trowel and left the molds in an area where they could set for 28 days without any disturbance.
10. The participants washed all the used equipment, returned them to Mr. Tedrick and cleaned the area of study.

Figure 28. Beams during construction and after completion

The fourth participant performed the same task in the second visit, dated April seventh, at the Architectural Ranch. The participant was provided with the XML schema of the beam construction. The fourth participant was able to construct the beam without any mentionable assistance.

EXPERIMENTAL WORK COMMENTS

This research was intended to deduce a minimal XML data set to build a concrete beam in three dimensions containing all information required for construction. With the help of this study the work were used to confirm the minimum information required by the participants to perform this task.

The participants chosen for this study were the graduate students of the Construction Science department of Texas A&M University. They all had a background of construction and were expected to carry out the task with minimum supervision. The expectations from the students before providing them the drawings were:

1. know the algorithm to prepare the specified concrete mix – M35 according to the ASTM standards
2. know the density of the concrete as 2400 kg/m^3
3. use a simple unit system in their calculations
4. know the standard proportions by weight of ingredients of concrete
5. know how to operate a concrete mixer
6. have enough site experience to avoid general errors and omissions

The list of expectations is mentioned in this section as it is the information which is not included in the drawings. Instead, it is expected that the builder will have at least this much knowledge of construction to be considered qualified for the task. The concern unrelated to this study is the inability of the graduate students to make simple concrete, without significant assistance. Nichols (2012c) noted a similar inability in the general undergraduate student in the Construction Science program.

DRAWING AND INFORMATION COMMENTS

This work was undertaken to determine the minimum level of information required to manufacture plain concrete beams so that an XML format could be developed to encapsulate the information.

Table 12 presents the information shown on the drawings. The XML file data presented in Table 4 and Table 5 is not repeated here.

Table 12. Table of information: comparison of information provided via drawings

Level of information	Hand drawn Drawing	AutoCAD Drawing	REVIT Drawing
Dimension of space	2D	2D	3D
Dimensions	Annotated	Annotated	Annotated
Scale	-	1:20	Fit to paper
Line Thickness	-	Used	Used
Rendering	-	-	Yes
Notes	-	Provided	Provided

All three drawings present sufficient information to provide the geometric information for construction of the simple beams. The advantages offered by AutoCAD and REVIT are the ability to quickly change the drawings and then re-plot the work. This is an interesting facet of the development of computer aided drafting, but it fails to address the very real problem of accurately and efficiently transferring data between programs. The data is important not the program.

The use of the XML Files for such a simple beam is a trivial example, but it shows that the information can be presented in a program neutral format, which is the key objective of the research work.

Table 13. Table of information: answers to participant's questions

Q. no.	Questions asked	Information provided	Comments
1	How to prepare M35 mix	Referred ASTM standard manual for mortar proportions	Instruction should be direction specific not performance specific
2	Weight by proportions of concrete ingredients	i. Gravel = 50 lb ii. Sand = 50 lb iii. Cement = 33 lb iv. Water = 14 lb	Expected knowledge
3	Density of concrete	$2.4 g/cm^3$ or $2400 kg/m^3$	Expected knowledge
4	How to operate the concrete mixer	Instructed by Mr. Tedrick	Expected experience
5	Location of water tap	Directed towards the tap	Expected to notice during the tour
6	Slump test	Omitted	From previous experience
7	Oiling the molds	No	From previous experience
8	Units used for density	g/cm^3 or kg/m^3	Expected knowledge

The participants given their background and previous experience should have been able to complete the work without significant assistance. The level of assistance and the observed errors points to a fundamental gap in their ability to perform the simplest of construction tasks, in this case make a concrete beam. Table 13 and table 14 summarize the record of assistance provided and errors made by the participants respectively. The errors of concern are:

1. use of different units systems

2. inability to operate a simple machine
3. inability to calculate the mass of required materials, allowing for the fact that the list of masses given to the participants is twice the required mass

Table 14. Table of errors

Errors	Affect	Resolution	Comments
Volume calculations in cm^3 equated to mass measured in kg	Huge numbers due to equating kg with cm^3	Switched to g/cm^3 from $kg/\ cm^3$	Expected to have knowledge of standard units
Unit for mass: $kg.m^3$	Wrong weights calculated, weighed material too less	Corrected unit used kg	Expected to avoid calculation mistakes
Failure to operate concrete mixer – white lever not switched on	Delay in task, failed to mix dry mortar	Machine turned on by Mr. Tedrick	Expected to have an experience of operating a petrol motor
Broke the mold	Clumsy to move to drying area	Stopped moving the mold and probed by wooden rod for compaction	Should have followed the instructions to lightly bang the mold for compaction

The results show a poor skill level in the participants, notwithstanding this problem the XML formatted data is sufficient to allow the manufacture of the concrete beam.

CHAPTER V

CONCLUSIONS

One is often left to ponder the vagaries of human nature. This study proved yet again that research results can surprise even the seasoned researcher. In this case, the interesting observation was the inability of the Construction Science graduate students to manufacture plain concrete given the materials, a working scale and a gasoline powered concrete mixer. This point is returned to later in this conclusions chapter. The objective of the research is to investigate the hypothesis:

A minimal markup language data set can be defined to create a concrete beam element containing all information required for construction by other than the designer.

The study method was to review the development of the language of construction from the earliest recorded times, in this case the Assyrian's use of geometry through to the recent development of Building Information Models. This review established the common elements to the documentation used to convey the information required, in this instance, to construct a simple plain concrete beam in a plywood form. A drawing was developed for each of the major stages of drafting development, one is hand drawn, one is drawn in AutoCAD and one is drawn in REVIT. A fourth system for documenting the beam was an XML file as shown in Table 4 and Table 5.

Four participants were selected to undertake the construction of the concrete beams given the four construction documents. The participants, Construction Science graduate students lacked the skills to complete the tasks without assistance in this case the researcher and the Architectural Ranch Manager. The multitude of errors observed in the method used by the participants is detailed in study, but the key conclusion is the lack of ability of the participants allowing for their educational level and background. Although the notable observation was that the fourth participant performed the same task with competent workability irrespective of the text format which lacked the visual aid.

The research work showed that the data for the construction of the concrete beam could be encapsulated in an XML file format. Further research is required to document an appropriate standard and establish this type of standard with the multitude of standards available at the moment.

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APPENDIX A

IRB APPROVAL

TEXAS A&M UNIVERSITY

DIVISION OF RESEARCH AND GRADUATE STUDIES - OFFICE OF RESEARCH COMPLIANCE

1186 TAMU, General Services Complex 979.458.1467
College Station, TX 77843-1186 FAX 979.862.3176
750 Agronomy Road, #3500 http://researchcompliance.tamu.edu

Human Subjects Protection Program Institutional Review Board

APPROVAL DATE: 08-Mar-2012

MEMORANDUM

TO:	BHANDARE, RUCHIKA 77843-3578
FROM:	Office of Research Compliance Institutional Review Board
SUBJECT:	Initial Review

Protocol Number:	2012-0070
Title:	BIM - Minimum Mathematical Configuration
Review Category:	Expedited
Approval Period:	08-Mar-2012 **To** 07-Mar-2013

Approval determination was based on the following Code of Federal Regulations:

Eligible for Expedite Approval (45 CFR 46.110): Identification of the subjects or their responses (or the remaining procedures involving identification of subjects or their responses) will NOT reasonably place them at risk of criminal or civil liability or be damaging to the their financial standing, employability, insurability, reputation, or be stigmatizing, unless reasonable and appropriate protections will be implemented so that risks related to invasion of privacy and breach of confidentiality are no greater than minimal.

Criteria for Approval has been met (45 CFR 46.111) - The criteria for approval listed in 45 CFR 46.111 have been met (or if previously met, have not changed).

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(7) Research on individual or group characteristics or behavior (including, but not limited to, research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices, and social behavior) or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation or quality assurance methodologies.

(Note: Some research in this category may be exempt from the HHS regulations for the protection of human subjects. 45 CFR 46.101(b)(2) and (b) (3). This listing refers only to research that is not exempt.)

Provisions:

Comments:

This research project has been approved. As principal investigator, you assume the following responsibilities

1. **Continuing Review:** The protocol must be renewed each year in order to continue with the research project. A Continuing Review along with required documents must be submitted 45 days before the end of the approval period. Failure to do so may result in processing delays and/or non-renewal.
2. **Completion Report:** Upon completion of the research project (including data analysis and final written papers), a Completion Report must be submitted to the IRB Office.
3. **Adverse Events:** Adverse events must be reported to the IRB Office immediately.
4. **Amendments:** Changes to the protocol must be requested by submitting an Amendment to the IRB Office for review. The Amendment must be approved by the IRB before being implemented.

5. **Informed Consent:** Information must be presented to enable persons to voluntarily decide whether or not to participate in the research project unless otherwise waived as noted above.

This electronic document provides notification of the review results by the Institutional Review Board.

APPENDIX B

SAMPLE EMAIL # 1

REQUEST TO PARTICIPATE IN
A RESEARCH STUDY – "BIM – Minimum Mathematical Configuration"
TEXAS A&M UNIVERSITY

Date:

Dear fellow COSC student/ faculty,

This email is to invite you for a study required for the completion of my Final Research Thesis. This study involves construction of a plain concrete beam – 4"wide X 6"deep X 3' long, using either of hand drawings, CAD drawings, Revit Drawings or XML schema as the set of drawing instructions.

The conceptual idea of this study is to provide design plans at with different standards of documentation and obtain same results. Participants will be observed as how easy it is for them to construct beams using the given construction document and determine the information they lack in each document to complete the work. Their inquiries to achieve the execution will be recorded and they will be included in the final XML schema. The XML schema then will contain the minimum information required to construct the beam. Your consent is necessary to participate in the study. This email is just to find out whether you would be interested to participate. If you are interested to participate in the study and respond to this email, I would follow up with you via email and would enclose the copies of consent form and the research proposal of my study. After reading the consent form and the proposal carefully you may accept or deny participating in the study.

Please feel free to include any additional comments you deem necessary or relevant to improving the program. Your response and time is greatly appreciated. Thank you!

Sincerely,
Ruchika Bhandare
Graduate Candidate, Department of Construction Science
Texas A&M University

APPENDIX C

SAMPLE EMAIL # 2

RESPONSE TO APPROVAL TO PARTICIPATE IN THE RESEARCH STUDY – "BIM – Minimum Mathematical Configuration"

TEXAS A&M UNIVERSITY

Date:

Dear fellow COSC student/ faculty,

Thank you for taking out time and responding to the previous email and agreeing to participate in the study. I have enclosed the copy of my research proposal and the consent form with this email. I insist on reading these documents carefully before approving to participate in the study.

After your perusal of these documents, if you decide to participate in the study, please send me an email informing about your consent and include your contact number so that I can fix up a meeting with you and my advisor and discuss about the study in person. Please bring a signed copy of your consent form, which I can store for my records.

Again, thank you for your response. I sincerely appreciate your time you are taking out for my research.

Sincerely,

Ruchika Bhandare
Graduate Candidate, Department of Construction Science
Texas A&M University

APPENDIX D

CONSENT FORM

PARTICIPANT CONSENT FORM FOR A RESEARCH STUDY

TEXAS A&M UNIVERSITY

PRIMARY RESEARCHER INFORMATION
Name: Ruchika Bhandare
Title: Graduate Student,
Email: bhandare.ruchika@tamu.edu
Tel: (979) 587 1767
Dept.: Construction Science, TAMU

INTRODUCTION

You are being invited to volunteer as a participant in a study being conducted at Texas A&M University. This consent form provides you with the information you will need when considering whether to participate in this study. If you decide to participate, you will be asked to sign this consent form which states that you have read the ***Summary of the Study***, that any questions you have about the study have been answered, and that you agree to participate. You will be given a copy of this form to keep for your records.

SUMMARY OF THE STUDY

Objective:

This research aims to propose a functional database as basic as XML, readable by all the BIM software to enable them to produce drawings eliminating the role of drafting. The ultimate goal is to facilitate absolute automation of BIM tool. This research aims to employ the use of XML database that can help in encoding documents in machine-readable format using minimum information required to recreate a design element. The hypotheses of the study are:

- A minimal XML data set can be defined to create a concrete frame in three dimensions containing all information required for construction.
- No current computer program uses a minimal XML data to record the data.

Test Procedure:

The conceptual idea of this study is to provide design plans at the different standards of documentation and to obtain same results. Participants will be observed as how easy it is for them to construct beams and determine the information they lack in the construction document to complete the work. Their inquiries to achieve the execution will be recorded and they will be included in the final XML schema.

To test the hypothesis a construction document of the concrete frame of a basic garage will be produced in following media and will be provided to each participant of the study to aid them to execute construction:

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- Assyrian geometry
  the beam drawing will be drafted with the help of basic geometric information, will be provided to the participant.

- AutoCAD drawing
  An AutoCAD drawing of the beam along with the detailed notes will be provided to the participant

- Revit
  A Revit drawing of the beam along with the detailed notes will be provided to the participant

- Analysis
  For the fourth participant, the task is to build the same set of beams at the Architectural Ranch without any set of instruction. This participant will be obliged to build the concrete frame 'only' by following the instructor's (my) algorithm of construction. This will help me identify the minimum information required by the participant to construct the garage's concrete framework. By recording the verbal information the participant required, I would be able to make the algorithm to create a XML schema.

- Final Test
  This XML schema will be provided to the fifth participant and will be asked to perform the same task and with the XML schema. The schema is insufficient if the participant needs any other information that the document does not contain. The XML schema will be tested until it contains the minimum information required to construct the concrete framework.

STUDY RISKS

Your participation in this study does not involve any major risk. You will be provided with a set of safety instructions and personal protective equipment (PPE) before you are sent on the site, including - eye protection, hard hats, steel toe shoe, rubber gloves and body protection suit. Before you enter the study site you will be examined for undertaking all the safety measures. You will be monitored by a 3rd Party for safety during the construction of beam.
If the set of safety measures and precautions are not followed during the construction there is a chance that you might injure yourself during beam construction.

STUDY BENEFITS

Benefits to you may include, better understanding of onsite concreting and you would learn how to construct a concrete beam

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Benefits to the construction industry may include the new potential format for exchanging contract documents.

COSTS TO THE SUBJECT
There are no costs for participating in this study.

COMPENSATION
The researcher is responsible for the to and fro commute of the participants from Department of Construction Science to the Architectural Ranch. All the PPE provided will be on the cost of researcher. No monetary compensation will be provided to any of the participant.

CONFIDENTIALITY
If you consent to participate in this study, your personal information will be kept confidential.

FUNDING
This research is not funded.

VOLUNTARY PARTICIPATION AND WITHDRAWAL FROM, THE STUDY
The decision whether to be in this study is entirely up to you. Participation is voluntary. You can refuse to participate, or withdraw from the study at any time, and such a decision will not affect your relationship with Texas A&M University or College of Architecture, either now or in the future. Nor will a refusal or withdrawal of participation result in the loss of any other benefits to which you are otherwise entitled. Signing this form does not waive any of your legal rights.

CONTACTS
Should you have any questions about this research or its conduct, you may contact:

Ruchika Bhandare
Primary Researcher
(979) 587 1767
bhandare.ruchika@tamu.edu

John M. Nichols
Primary Advisor
(979) 845 6541
jm-nichols@tamu.edu

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STATEMENT OF CONSENT

- I have read the research proposal.
- I confirm that I have read and I understand all the provided information for this study.
- I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily.
- I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason, without my medical care or legal rights being affected.
- I understand that relevant sections of any of my medical notes and data collected during the study may be looked at by responsible individuals from Dept. of Construction Science, Texas A&M University from regulatory authorities, where it is relevant to my taking part in this research. I give permission for these individuals to have access to my records.
- I agree to take part in the above research study.
- I certify that I am 18 years old or older.
- I also understand that if I choose not to participate, the data collected while I am undertaking the study will be deleted once it is determined that the participant for this study did not sign a consent form. I also understand that if I choose not to participate, that my data may not be protected by the Certificate of Confidentiality, but again, the data will be deleted as soon as it is determined that the participant for this study did not sign a consent form.

______________________________ ________________________________ _________

Participant (Print Name) Signature Date

______________________________ ________________________________ _________

Researcher (Print Name) Signature Date

==

The Participant must be provided with a Copy of this Consent Form

APPENDIX E

FORM OF CONFLICT OF INTEREST

TEXAS A&M UNIVERSITY HUMAN SUBJECTS PROTECTION PROGRAM

CONFLICT OF INTEREST STATEMENT

Name of Principal Investigator: **Ruchika Bhandare**	**HSPP Office use only**
Department: **COSC**	
Email Address: **bhandare.ruchika@tamu.edu**	
Telephone Number: **(979) 587 1767**	
Mail Stop: **3137**	
Please check if you are the: ☒ Principal Investigator ☐ Co-Investigator – **N/A**	
Investigator Name:	
Department:	
Email Address:	
Telephone Number:	

Funding Agency: **N/A**

Funding Administrator: HSC ☐ RF ☐ TAES ☐ TEES ☐ TAMU ☐ TTI ☐ OSRS ☐

Title of Project: BIM- Minimum Mathematical Configuration

All Principal Investigators and Co-Investigators must complete a separate Conflict of Interest Statement, and comply with the conditions or restrictions imposed by the University to manage, reduce, or eliminate actual or potential conflicts of interest or forfeit IRB approval and possible funding. This disclosure must also be updated annually when the protocol is renewed.

Carefully read the following statements and check the appropriate box after considering whether you or any member of your immediate family* have any conflicts of interest.

☒ **I have no conflict of interest related to this project.**

☐ **I have a non-financial conflict of interest related to this project.** Please describe:

☐ **I have a financial conflict of interest related to this project.** Please provide information regarding the financial interest as described below and as it applies to this project. All items must be marked confidential and provided in a separate envelope or folder.

a) A financial interest in the research with value that cannot be readily determined;
b) A financial interest in the research with value that exceeds $10,000.00;
c) Have received or will receive compensation with value that may be affected by the outcome of the study;
d) A proprietary interest in the research, such as a patent, trademark, copyright, or licensing agreement;
e) Have received or will receive payments from the sponsor that exceed $10,000.00 in a specific period of time;
f) Being an executive director of the agency or company sponsoring the research;
g) A financial interests that requires disclosure to the sponsor or funding source; or
h) Have any other financial interests that I believe may interfere with my ability to protect participants.

*Immediate family is considered to be a close relative by birth or marriage including spouse, siblings, parents, children, in-laws and any other financial dependents.

(Ruchika Bhandare, Principal Investigator)	**02/27/2012**
Signature of Principal/Co-Principal Investigator	**Date**

Form version date: 09/01/11 modified by: dg

APPENDIX F

XML SCHEMA

The XML File is shown in methodology. The XLS Schema for the XML File Type is shown in Figure 29 to Figure 32 below.


```xml
<?xml version="1.0" encoding="utf-8"?>
<xs:schema attributeFormDefault="unqualified" elementFormDefault="qualified" targetNamespace="http://Concrete" xmlns:xs="http:/
    <xs:element name="Beams">
        <xs:complexType>
            <xs:sequence>
                <xs:element name="Beam">
                    <xs:complexType>
                        <xs:sequence>
                            <xs:element name="Dimensions">
                                <xs:complexType>
                                    <xs:sequence>
                                        <xs:element name="First" type="xs:unsignedShort" />
                                        <xs:element name="Second" type="xs:unsignedByte" />
                                        <xs:element name="Third" type="xs:unsignedByte" />
                                    </xs:sequence>
                                </xs:complexType>
                            </xs:element>
                            <xs:element name="CoordinateSystem">
                                <xs:complexType>
                                    <xs:sequence>
                                        <xs:element name="Form" type="xs:string" />
                                        <xs:element name="Units" type="xs:string" />
                                        <xs:element name="Origin" type="xs:string" />
                                        <xs:element name="X" type="xs:string" />
                                        <xs:element name="Y" type="xs:string" />
                                        <xs:element name="Z" type="xs:string" />
                                    </xs:sequence>
                                </xs:complexType>
                            </xs:element>
                            <xs:element name="Materials">
                                <xs:complexType>
                                    <xs:sequence>
                                        <xs:element name="PC">
                                            <xs:complexType>
                                                <xs:sequence>
                                                    <xs:element name="Strength" type="xs:unsignedByte" />
                                                    <xs:element name="Units" type="xs:string" />
                                                    <xs:element name="Test" type="xs:string" />
                                                    <xs:element name="Standard" type="xs:string" />
                                                    <xs:element name="DefaultMix">
                                                        <xs:complexType>
                                                            <xs:sequence>
                                                                <xs:element name="Massunits" type="xs:string" />
                                                                <xs:element name="Sizeunits" type="xs:string" />
                                                                <xs:element name="FineAggregate">
                                                                    <xs:complexType>
                                                                        <xs:sequence>
                                                                            <xs:element name="Mass" type="xs:unsignedByte" />
```


Figure 29. XLS schema for XML file – I

```
                        <xs:element name="maxSize" type="xs:unsignedByte" />
                      </xs:sequence>
                    </xs:complexType>
                  </xs:element>
                  <xs:element name="CoarseAggregate">
                    <xs:complexType>
                      <xs:sequence>
                        <xs:element name="Mass" type="xs:unsignedByte" />
                        <xs:element name="maxSize" type="xs:unsignedByte" />
                      </xs:sequence>
                    </xs:complexType>
                  </xs:element>
                  <xs:element name="Water">
                    <xs:complexType>
                      <xs:sequence>
                        <xs:element name="Type" type="xs:string" />
                        <xs:element name="Mass" type="xs:unsignedByte" />
                      </xs:sequence>
                    </xs:complexType>
                  </xs:element>
                  <xs:element name="Cement">
                    <xs:complexType>
                      <xs:sequence>
                        <xs:element name="type" type="xs:string" />
                        <xs:element name="Mass" type="xs:unsignedByte" />
                      </xs:sequence>
                    </xs:complexType>
                  </xs:element>
                </xs:sequence>
              </xs:complexType>
            </xs:element>
          </xs:sequence>
        </xs:complexType>
      </xs:element>
      <xs:element name="Formwork">
        <xs:complexType>
          <xs:sequence>
            <xs:element name="type" type="xs:string" />
            <xs:element name="Thickness" type="xs:unsignedByte" />
            <xs:element name="units" type="xs:string" />
          </xs:sequence>
        </xs:complexType>
      </xs:element>
      <xs:element name="Finish" type="xs:string" />
    </xs:sequence>
  </xs:complexType>
</xs:element>
```

Figure 30. XLS schema for XML file – II

```
    </xs:element>
    <xs:element name="Designer" type="xs:string" />
    <xs:element name="Date">
        <xs:complexType>
            <xs:sequence>
                <xs:element name="Design">
                    <xs:complexType>
                        <xs:sequence>
                            <xs:element name="Year" type="xs:unsignedShort" />
                            <xs:element name="Month" type="xs:unsignedByte" />
                            <xs:element name="Day" type="xs:unsignedByte" />
                            <xs:element name="Completed" type="xs:string" />
                        </xs:sequence>
                    </xs:complexType>
                </xs:element>
                <xs:element name="Built">
                    <xs:complexType>
                        <xs:sequence>
                            <xs:element name="Year" type="xs:unsignedByte" />
                            <xs:element name="Month" type="xs:unsignedByte" />
                            <xs:element name="Day" type="xs:unsignedByte" />
                            <xs:element name="completed" type="xs:string" />
                        </xs:sequence>
                    </xs:complexType>
                </xs:element>
                <xs:element name="Inspected">
                    <xs:complexType>
                        <xs:sequence>
                            <xs:element name="Year" type="xs:unsignedByte" />
                            <xs:element name="Month" type="xs:unsignedByte" />
                            <xs:element name="Day" type="xs:unsignedByte" />
                            <xs:element name="completed" type="xs:string" />
                        </xs:sequence>
                    </xs:complexType>
                </xs:element>
            </xs:sequence>
        </xs:complexType>
    </xs:element>
    <xs:element name="City" type="xs:string" />
    <xs:element name="Zip" type="xs:unsignedInt" />
    <xs:element name="Country">
        <xs:complexType>
            <xs:sequence>
                <xs:element name="Name" type="xs:string" />
            </xs:sequence>
        </xs:complexType>
    </xs:element>
</xs:sequence>
```

Figure 31. XLS schema for XML file – III

```
                        <xs:attribute name="id" type="xs:unsignedByte" use="required" />
                        <xs:attribute name="type" type="xs:string" use="required" />
                    </xs:complexType>
                </xs:element>
            </xs:sequence>
        </xs:complexType>
    </xs:element>
</xs:schema>
```

Figure 32. XLS schema for XML file – IV

VITA

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	M.S., Construction Management, Texas A&M University, College Station, Texas, 2012