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Applying Cognitive Principles to the Delivery of Engineering Information by Different Mediums

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APPLYING COGNITIVE PRINCIPLES TO THE DELIVERY OF ENGINEERING INFORMATION BY DIFFERENT MEDIUMS

DISSERTATION

A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the College of Engineering at the University of Kentucky

By
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Lexington, Kentucky

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Lexington, Kentucky

2013

ABSTRACT OF DISSERTATION

APPLYING COGNITIVE PRINCIPLES TO THE DELIVERY OF ENGINEERING INFORMATION BY DIFFERENT MEDIUMS

Construction project performance and worker productivity are often tied to the availability and effective presentation of information, tools, materials, and equipment. While advancements in technology have improved much of the processes on a construction project, the medium of information dissemination at the construction work face has consistently relied on the use of two dimensional drawings and specifications.

Industry initiatives are driving increased collaboration through three dimensional BIM (Building Information Modeling) models. However, the added dimension partially loses its effect when presented on a two dimensional computer monitor. Other computer forms of presentation intended for mobility (PDAs, laptops, and tablets) can be difficult to use in the field due to glare, durability in a harsh working environment, and the required skill level for effective use. Three dimensional (3D) physical printers now provide the capability to develop scaled and color models of a project directly from a BIM model. 3D physical printers represent a potential transformative change of providing engineering information to construction crews, but how to develop 3D models that leverage the cognitive benefits of viewing engineering information in a physical 3D form is unknown.

The primary contribution to the overall body of knowledge of this dissertation is to scientifically examine the effect that different engineering information mediums have on an individual's cognitive ability to effectively and accurately interpret spatial information. First, the author developed a robust scientific experiment for construction practitioners and students to complete. This experiment included outcomes measures on mental workload, cognitive demand, productivity, efficiency, demographics, and preferences. After collecting data, the author analyzed the outcomes through a series of statistical analyses to measure the differences between groups and quantify the affect and relationship among key variables.

From the results, there are statistically significant improvements in productivity and efficiency of practitioners and students when using a physical model compared to two dimensional drawings and a three dimensional computer model. In addition, the average cognitive demand for a physical model was lower than the average cognitive demand for two dimensional drawings and three dimensional computer model.

KEYWORDS: Information Delivery, Cognitive Task Demands, Construction Labor Strategies, Additive Manufacturing, Building Information Modeling (BIM) Applications in Construction

Gabriel B. Dadi
Student's Signature

Date

APPLYING COGNITIVE PRINCIPLES TO THE DELIVERY OF ENGINEERING INFORMATION BY DIFFERENT MEDIUMS

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Date

This doctoral dissertation is dedicated first and foremost to my parents, Biratu and Clara,
my wife, Katie, and my brother, Daniel.

I would also like to dedicate this work to my extended family, Habte, Almaz, Sharon,
Micheal, Hailu, Askale, Aimee, Chuck, David, Pam, David, Emily, Chase, Mamie,
PaBear, Bo, Cynthia, Harrison, Bill, Kelli, Will, Jacob, Riley, and Nick.

ACKNOWLEDGMENTS

This is work is the summation of countless hours of guidance, motivation, and assistance of many individuals. I must first acknowledge the support from my advisors and co-chairs, Dr. Paul Goodrum, Dr. Tim Taylor, and Dr. Bill Maloney through my time at the University of Kentucky. Their leadership and knowledge has been invaluable and will be reflected as I shift towards a mentoring role. Paul always made sure to keep me up to date with the peloton from the Tour and eating challenges from TV. I will cherish several memories from eventful travel opportunities, specifically the final hurrah in Baltimore with the burdensome Graffiti Wall. Tim and I shared copious amounts of pad thai during this journey while we discussed the merits of college sports. Bill was always ready to share his thoughts on the joys of academic life and higher education, and of course, Ann Arbor and his Wolverines. I owe them each a great deal of gratitude and appreciation for their wisdom and knowledge.

I must also recognize the rest of my committee, Dr. Melody Carswell, and Dr. Issam Harik. Only with their supervision and insights do I complete this endeavor. In their own way, each professor has shown me the expectations and dedication that is necessary to be successful as an academic. I am grateful to have had their expertise at my disposal during my scholarly career.

In addition to the technical guidance, I would like to acknowledge my parents, Biratu and Clara Dadi. It has been with their guidance, inspiration, support, and love that I complete this work and overcome challenges.

I would also like dedicate this study to my wife Katie. In her, I have the comfort and motivation to strive for the best that life affords. She has been a loving, supportive partner in the truest sense of the word.

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CHAPTER ONE: INTRODUCTION

1.1. Background and Motivation

Construction industry spending is annually one of the largest sector contributions to the gross domestic product (GDP) of the United States. In 2010, the industry was responsible for more than $800 billion in spending (United States Census Bureau, 2011), while also employing over 7 million individuals (Bureau of Labor Statistics, 2010). As a significant component, the industry's performance is critical to the success and well-being of the country's economy. Oglesby et al. (1989) divides construction performance into four categories: productivity, safety, timeliness, and quality. Often interrelated, these factors are the drivers of individual project performance, as well as the industry as a whole. In particular, construction productivity has been a focus of many academic studies, and improving productivity is an active research topic within the construction academic community.

A construction project's stakeholders are concerned with productivity and adopt policies, practices, and procedures to improve productivity. However, a project's productivity ultimately hinges on workface practices. If construction practitioners are not equipped with the necessary tools, information, materials, and equipment to effectively perform their tasks, the productivity of the project will be negatively affected.

Many practitioners feel that information delivery, and further design or construction drawing management, is a significant factor to efficiently performing their job (Construction Industry Institute, 2006; Dai et al., 2009a; Dai et al., 2009b; Mourgues and Fischer, 2008; and Rojas, 2008). Schwartzkopf's (2004) synthesis of lost productivity studies found several reports that listed engineering drawings and information as sources of lost productivity (Mechanical, 1986; Thomas and Smith, 1990). Prior research found inefficiencies from drawing management exist due to errors in the drawings, availability of the drawings, slow management response to questions, legibility, and omission of necessary information on the documents (Construction Industry Institute, 2006; Dai et al., 2009a; and Dai et al., 2009b). Poor information delivery has the potential to create a ripple effect throughout the project. Mourgues and Fischer (2008) argue that communication of project information to the workface is ineffective and can negatively impact quality, safety, and productivity. Rojas (2008) and Schwartzkopf (2004) discuss inefficiencies from design drawings ultimately leading to increased rework on the project. Supervisors and foremen then become focused on correcting engineering errors and rework instead of planning future work and focusing on crew performance.

This becomes an issue of errors in communication. The typical communication process (outlined in Figure 1.1) involves a sender (designer), receiver (supervisor or foreman), and a message (construction drawing). This model has a sender encode the desired content into a message that must then be decoded by the receiver into an interpretation of the desired content. These intermediary steps of encoding and decoding a message present an opportunity for noise to distort the actual message. The message channel flows from the sender to the receiver either verbally or nonverbally (Shannon and Weaver, 1948; Schramm, 1954; and Berlo, 1960). Research that understands the steps that involve noise and present solutions to limit the existence and opportunities for noise can greatly improve the flow of communication.

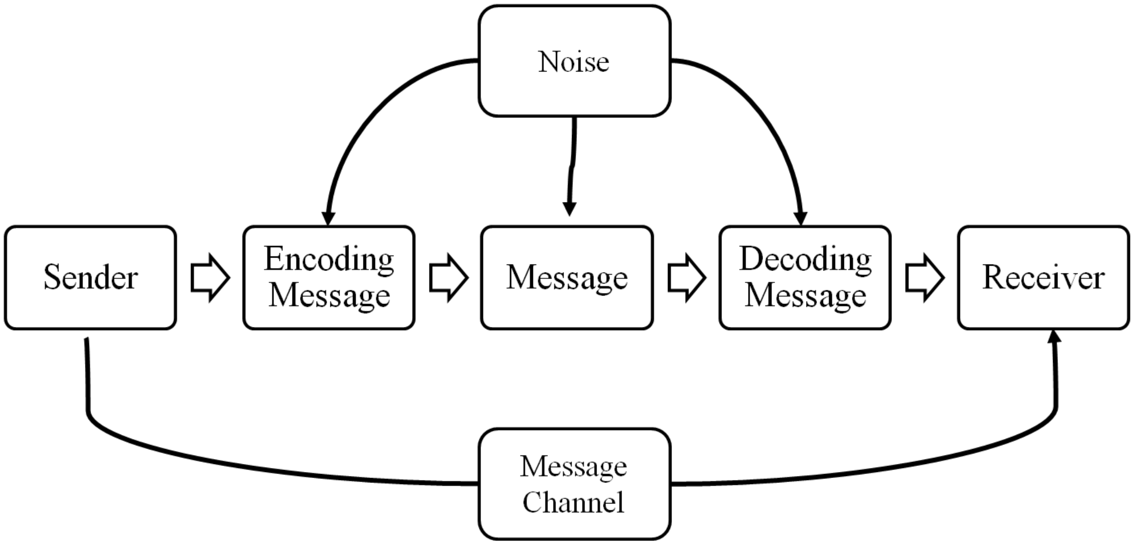

Figure 1.1 Standard Model of Communication (adapted from Shannon and Weaver, 1948; Schramm, 1954; and Berlo, 1960)

While these issues are well known through the presented, discussed literature, there is an opportunity to rethink the way spatial information is presented to the construction field. There has been a new focus on work face practices through some of the more prominent construction research funding agencies. The Construction Industry Institute (CII) and Fiatech (Fully Integrated and Automated Technologies) have recently funded significant efforts towards studying how information is presented to the work face. Through CII's RT 272 "WorkFace Planning, from Design through Site Execution" and Fiatech's research teams "Advanced, Fully Integrated WorkFace Planning & Control", the research community has an interest in rethinking information delivered to the work face.

However, no studies have surfaced from these research teams regarding the way spatial information is presented. With new technologies such as tablets, 3D printers, and wearable computers, there is an opportunity to understand how certain information can be best presented. This research begins to understand the cognitive interpretations and abilities of practitioners in dealing with a simple structure through 2D drawings, a 3D computer model, and a 3D printed physical model.

1.2. Research Objectives

The primary objective of this research is to evaluate the effects of different mediums on the human cognitive interpretation of engineering information. This research will help management strategically deliver information in the most effective manner to increase the efficiency of information dissemination. Within the primary objective, several secondary or supportive objectives will also be addressed in the coming chapters. The supportive objectives are defined as:

1. Identify the cognitive principles behind spatial information processing for engineering project information;
2. Identify the uses of the different information mediums available for construction practitioners;
3. Develop a standard model for evaluating the cognitive interpretation of engineering information;
4. Develop and test assessment forms and a study for testing the effectiveness of the model; and
5. Identify the cognitive traits that are best served by different mediums.

1.3. Research Scope

The principle outcome of this doctoral research is to identify the effectiveness of different mediums of information presentation. The information delivery formats tested are traditional construction two dimensional drawings, a computer three dimensional interface (Building Information Modeling), and a physical scale model. The research is multi-disciplinary and heavily leverages previous studies in cognitive testing and mental workloads for validation and reliability. This study used the NASA-TLX (National Aeronautics and Space Administration Task Load Index) as the measure for cognitive workload. Subjects were asked to reconstruct the information displayed in one of the mentioned formats using a set of simple building elements, and then were administered the NASA-TLX that measures mental demand, physical demand, temporal demand, effort, performance, and frustration (Carswell et al., 2005). In addition objective measures were obtained in the form of time to completion and a five-minute rating. Time to completion of the task provides a look into the information delivery formats that lend to quicker completion. The five-minute rating yields percent of time spent on non-direct work activities, or activities resulting in rework. To conduct a five-minute rating, a time sheet broken down into subsets of time and then columns for notation of the activity classification was created. The classification categories are direct work, indirect work, rework, and delay due to rework. Direct work is defined as any physical building of the model towards the final product. Indirect work is defined as any activities performed towards the end result that is not physically building the model. This includes time getting familiar with the building elements, and manipulating and processing the information delivery format. Rework includes any disassembling or reassembling of a previously built portion of the model. Finally, delay due to rework includes time spent reprocessing the information delivery medium after rework occurs.

1.4. Research Methodology

Several methods to meet the research objectives were considered prior to execution. At the core of the research scope is an evaluation of cognitive performance for construction craft foremen. Therefore previous research in cognitive psychology was examined to determine the proper method of evaluation. From the literature review and consultations with a cognitive psychologist, an experiment was developed for use.

The test asks subjects to complete a model building exercise to replicate the model shown on a given information format. Three types of information delivery formats for the same model were developed; two dimensional drawings, a three dimensional computer interface, and a physical model.

The exact test procedure was developed and approved in accordance with proper IRB policies and procedures. This process is discussed further in Section 4.4. Similar studies have been identified (Carswell et al., 2005; Carswell et al., 2010; ChanLin, 1996; Miller and Doyle, 1987), and their methods will be incorporated in this study. Subjects for the study have been recruited from local commercial contractors throughout the state of Kentucky, as well as undergraduate and graduate civil engineering students at the University of Kentucky. A statistical analysis of the outcome measures yielded reliable and validated results that are further discussed to develop the recommendations and conclusions in Chapter 6.

1.5. Dissertation Organization

This dissertation is divided into nine chapters. Chapter one presents an introduction, objectives, scope, and methodology for the research. Chapter two delves into the research topic through an extensive literature review. The literature review draws upon research published across various construction segments to present the inherent limitations of current information delivery methods and its effect on labor productivity. Alternative methods of information delivery in previous and recent practice are presented. The cognitive principles that drive effectiveness of instructional design and information processing are outlined in chapter three to set up the means of study. Chapter four, in detail, presents the possible methods for the study, the selected procedure, and a discussion on the merits of the selected procedure. Chapter five submits the results and analysis of the obtained data through various statistical tools. Chapter six identifies conclusions and recommendations from the results, as well as suggestions for future work in the area. Finally, the remainder of the contents contains appendices, bibliography, and a short vita.

CHAPTER TWO: BACKGROUND AND LITERATURE REVIEW

2.1. Construction Productivity

The construction industry is at a disadvantage in the overall economy of the United States. Due to changes in real output and differences in accounting procedures, there is no industry level measure of productivity. The Bureau of Labor Statistics (BLS) maintains labor and/or multifactor productivity data for the business, nonfarm business, manufacturing, mining, utilities, wholesale, retail trade, line-haul railroads, and air transportation industries (Bureau of Labor Statistics, 2012). This makes it difficult to track progress, benchmark, and measure effects of policies across the industry. Several efforts have occurred to gauge productivity of the industry with varying conclusions. Using macro-scale data, Stokes (1981), Allen (1985), and Triplett and Bosworth (2004) concluded that the productivity of the industry has been declining for quite some time. Teicholtz (2001) illustrates how poorly the industry has performed relative to non-farm industries (Figure 2.1). In the years studied, the industry has declined in productivity while also falling behind the gap of the non-farm industries. However, others have found that productivity of the industry has actually improved over the same time frame using activity level measurements (Goodrum et al, 2002a). The difference in the studies is in the measurement of construction productivity at a macro level versus an activity level. Macro level productivity figures are based on aggregate measures that do not control for inflation in measuring real output.

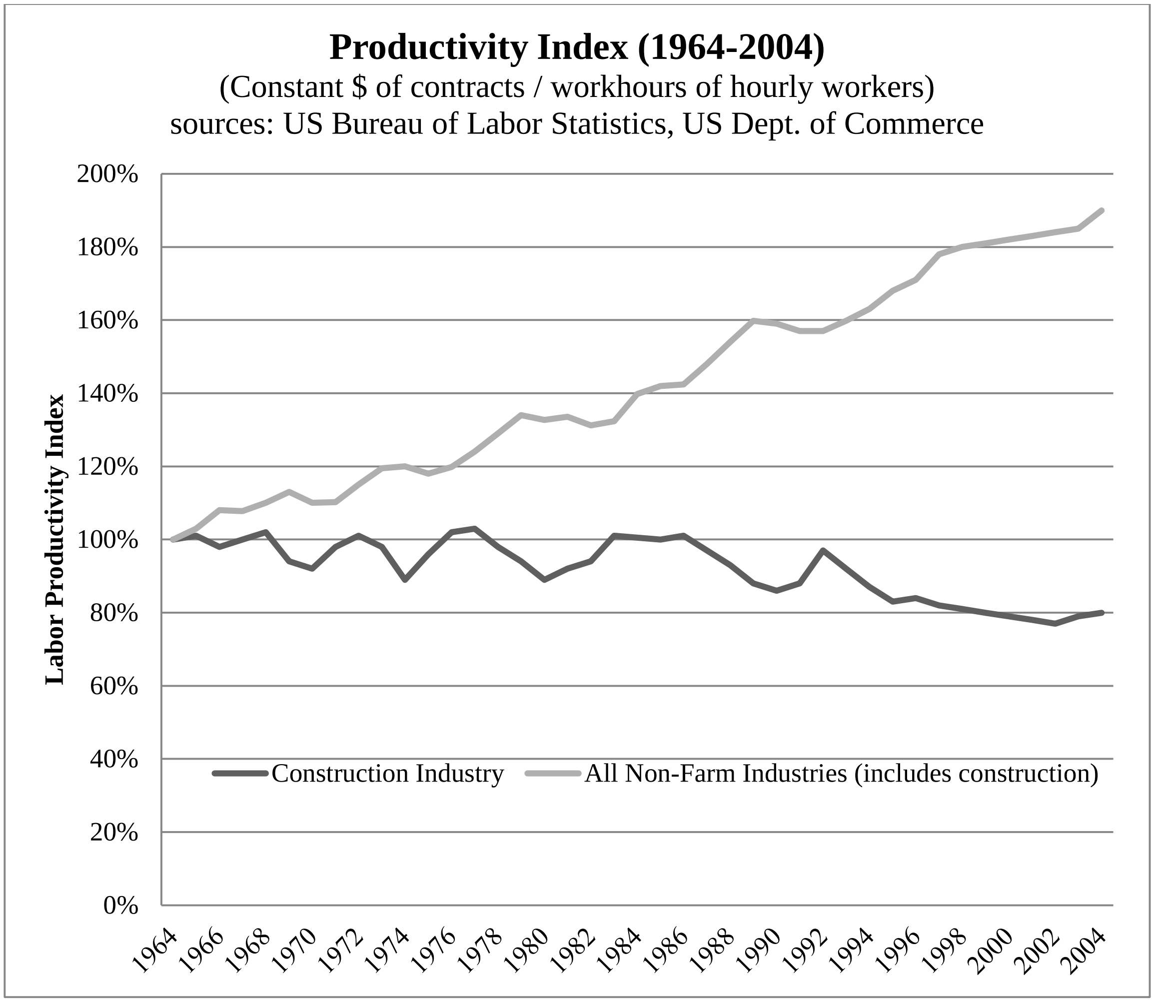

Figure 2.1 Productivity Index for Construction Industry and Non-Farm Industry from 1964-2004 (Teicholtz, 2001; Eastman, 2008)

However at a project level, productivity figures are more diligently kept, although still inconsistent company to company. With profit margins near 3%, firms must do what they can to track their performance and make necessary changes (Cooper and Lee, 2009). Many construction project stakeholders are concerned with productivity and adopt policies, practices, and procedures to improve productivity. However, a project's productivity ultimately hinges on workface practices. If the construction practitioners are not equipped with the necessary tools, information, materials, and equipment to effectively perform their tasks, the productivity of the project will be negatively affected.

2.1.1. Information Delivery and its Effect on Construction Productivity

Many practitioners feel that information delivery, and further design or construction drawing management, is a deterrent to efficiently performing their job (Construction Industry Institute, 2006; Dai et al., 2009a; Dai et al., 2009b; Mourgues and Fischer, 2008; Rojas, 2008; and Schwartzkopf, 2004). The main inefficiencies from drawing management exist due to errors in the drawing, availability of the drawings, slow management response to questions, legibility, and omission of necessary information on the documents (Construction Industry Institute, 2006; Dai et al., 2009a; and Dai et al., 2009b).

The National Economic Development Office (NEDO) in the United Kingdom sought to identify ways to improve quality on building projects. Two main factors that affected quality were lack of coordination in design, unclear and missing documentation (NEDO, 1987; NEDO, 1988). Some of the issues result from the difference in the message intended versus the message received. The format and intent of drawings is easier to comprehend by the architect or engineer that creates the drawing than it is for the contractor and his/her workforce that has to interpret the message (Emmitt and Gorse, 2003; Issa, 1999). This problem is magnified when the contractor must reference several different drawings to understand the design intent for a particular building element. Further, different symbols and terminology can be used by various designers that can also lead to confusion and complications (Emmitt and Gorse, 2003).

Poor information delivery has the potential to develop a ripple effect throughout the project. Mourgues and Fischer (2008) argue that communication of project information to the workface is ineffective and can negatively impact quality, safety, and productivity. Rojas (2008) and Schwartzkopf (2004) discuss inefficiencies from design drawings ultimately leading to increased rework on the project. Borcherding et al. (1980) found that rework was one of the three most significant drivers to poor productivity and decreased morale, oftentimes as a result of poor engineering information design. The Construction Industry Institute (2011a) found that design, engineering, instruction, and monitoring accounted for 29.08% of the total amount of rework on an analysis of over 2,000 records from the industrial sector. Supervisors and foremen then become focused on correcting engineering errors and rework instead of planning future work and focusing on crew performance. In the highway construction sector, an analysis of change orders on 610 projects showed that omissions of information led to a 4.53% increase in original contract amount (Taylor et al., 2012). With 40% of the total construction cost being in direct and indirect craft labor, there is a need to maximize efficiency and reduce non-value adding activities of the workers (Construction Industry Institute, 2011).

Recognizing the opportunity for improved work instructions or information delivery is insufficient if solutions or recommendations cannot be made. Some literature has identified characteristics of effective work instructions. Emmitt and Gorse (2003) suggest it is important for work instructions to be clear, concise, complete, correct, meaningful, relevant, accurate, and timely. They continue further in offering a checklist for selecting the proper communication medium:

- Does the medium help transfer understanding?
- Are all the parties who need the information able to access it?
- Will multiple formats (levels) of information help understanding or cause confusion?

- Is the medium used to exchange ideas or is it used to convey instructions?
- Does the medium assist in providing the level of informal or formal exchange required?
- Does one format of information supersede or replace a previous format?
- Will the medium be able to be used where it is required? (for example computer screens are difficult to read on site when the sun is shining or it is raining)

While these concepts are helpful in recognizing the characteristics of effective communication tools, the next step needs to be taken. What opportunities exist to support and improve the current and traditional method of information delivery? This dissertation investigates the use of another method of information delivery in physical models of construction projects.

As previously mentioned, increased rework is a direct consequence of poor information delivery. Rework is feared in the construction industry for its effect on schedule, cost, quality, and overall project performance. The following section discusses the negative effects rework has on capital construction projects.

2.2. Construction Rework

With errors from interpreting drawings or incorrect designs, the level of rework, either discovered or undiscovered, increases. Fayek et al. (2003 and 2004) found that errors and omissions in design documents contributed to 69% of the frequency and 78% of the monetary impact of engineering review causes of rework. Errors from design and instructions caused 29% of the total amount of construction rework from a survey of 926 rework events in 2008 according to Zhang (2009). Rework, as defined by Love et al.

(2000), is “the unnecessary effort of re-doing a process or activity that was incorrectly implemented the first time. It is an endemic feature of the construction procurement process and is a primary factor that contributes to time and cost overruns in projects.” Simply, rework triples the effort, at a minimum that should be required; the initial work, the work required to extract the error, and the final work to reinstall the element correctly. The cost of incurring rework directly has been found to be 10-15% of the total project costs, which does not include the indirect effects of schedule delays, litigation costs, and poor quality (Love et al., 2000; Zabilski and Reinschmidt, 1996). With the industry spending $800 billion in project costs in 2010 (United States Census Bureau, 2011), the total rework costs for the industry could conservatively be estimated at $8 billion (10%).

2.2.1. Strategic Level Studies of Construction Rework

Rework significantly affects the cost performance of a project, as previously discussed. Further, rework also impacts the project schedule, in particular undiscovered rework. When rework goes unreported or unnoticed, the effect it ultimately has multiplies. This phenomenon has been frequently studied in the field of system dynamics. System dynamics (SD) seeks to accurately model the factors inherit in a system, and then studies the changes over time. Love and Li (2000) suggest that system dynamic modeling is “useful for managing complex processes that involve changes over time and are dependent on the feedback, transmission, and receipt of information.”

A specific phenomenon related to negative project impacts from undiscovered rework that has come out of the SD literature is the 90% syndrome discussed in Ford and Sterman (2003). This is the concept that projects progress until approximately the 90%

completion mark but then hits an unforeseen wall. The effort that goes into the last 10% is disproportionally higher than the previous 90%, and the project finishes about twice as longer as originally projected. In Figure 2.2, an actual sample project in Ford and Sterman (2003) shows the 90% syndrome in practice. The project progresses slightly behind the planned progress up until the 80-90% range where it takes about 30 weeks it finish the last 10% (45 weeks for the previous 90%). The reason behind the difficulty is in undiscovered rework that shows up at this stage in the project lifecycle. Inspections and punch lists often find the need to correct mistakes made much earlier in the project. This has a compounding effect on all activities that occurred after or around the error(s) (Lyneis and Ford, 2007; Taylor and Ford, 2006; Taylor and Ford, 2008).

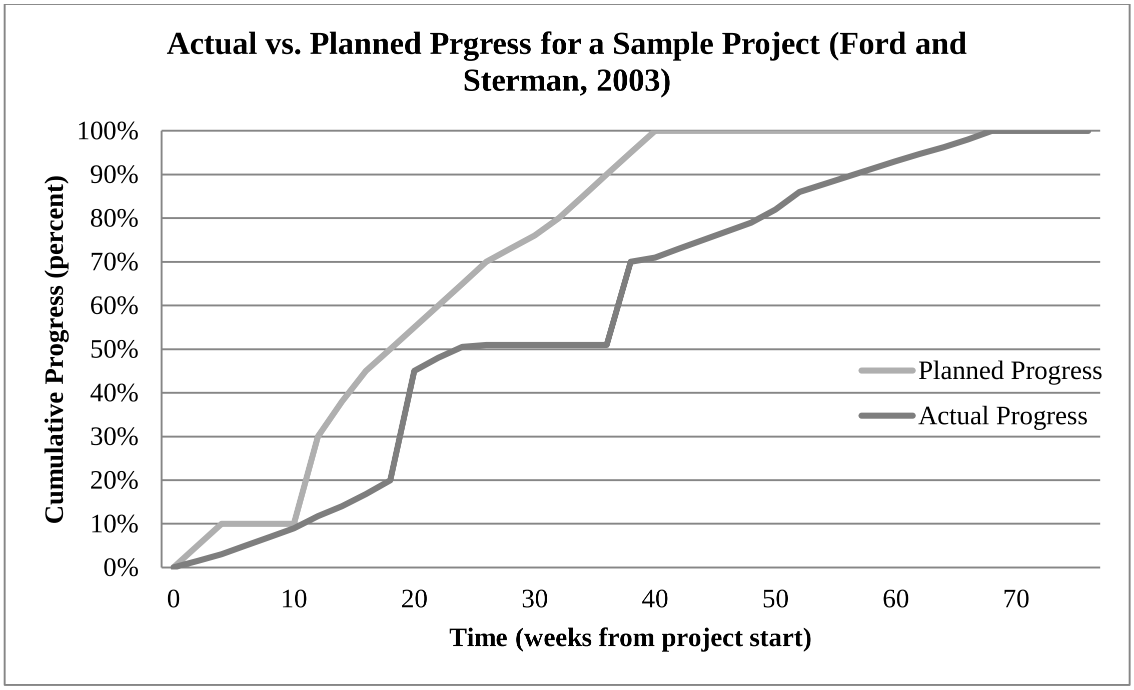

Figure 2.2 Actual vs. Planned Progress for a Sample Project (Ford and Sterman, 2003)

2.2.2. Construction Rework in a Project Lifecycle

While it has been shown that poor design communication leads to higher levels of rework, the time to address the problem must be early in the project lifecycle. As seen in the cost influence curve in Figure 2.3, management’s ability to influence cost is higher earlier in the project lifecycle. As the project develops, the ability to reduce costs decreases as expenses are incurred. It is important to implement strategies and best practices early on, so that savings and timeliness are realized. This is further validated when investigating the costs created from rework in the design and construction phases. Love and Li (2000) found that 46% of cost deviations from rework occurred in the design phases, while only 22% were created during construction.

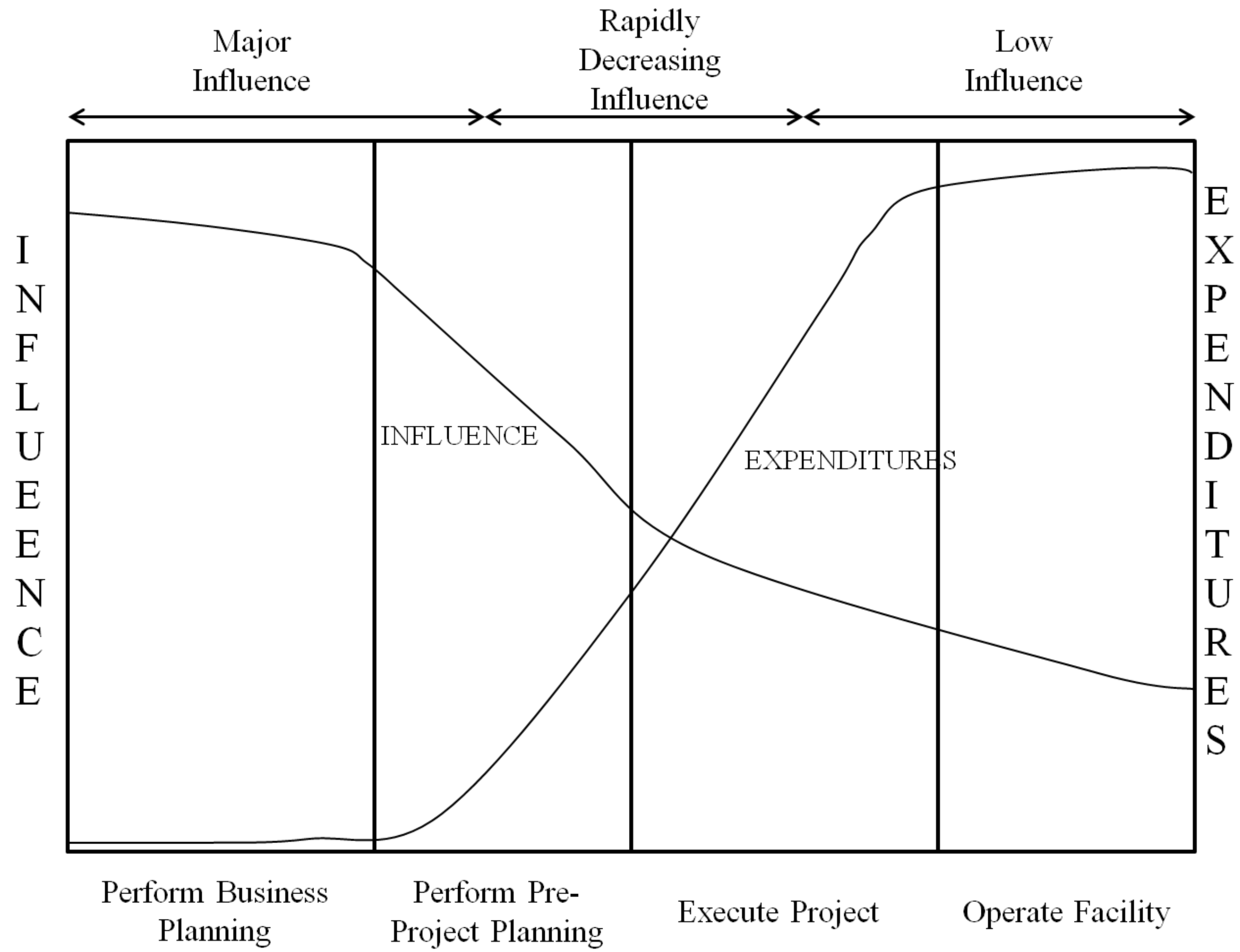

Figure 2.3 Cost Influence Curve (Barrie and Paulson, 1978)

2.3. Traditional Delivery of Engineering Information

Many practitioners feel that information delivery, and further design or construction drawing management, is a deterrent to efficiently performing their job (Construction Industry Institute, 2006; Dai et al., 2009a; Dai et al., 2009b; Mourgues and Fischer, 2008; Rojas, 2008; and Schwartzkopf, 2004). Design and construction drawings frequently contain errors, omissions, and potentially illegible language. The resulting confusion or poor clarity can be attributed to differences in individuals. The creator of the documents may not design exactly how the reader interprets. The format and intent of drawings is easier to comprehend by the architect or engineer that creates the drawing than it is for the contractor that has to interpret the message (Emmitt and Gorse, 2003). Further, management of the drawings can lead to unavailability and slow responses to questions or clarification of the information on documents (Construction Industry Institute, 2006; Dai et al., 2009a; Dai et al., 2009b; and Borcherding et al., 1980). In addition, workers frequently must reference several drawings to complete the reference for a task, and therefore must encode several pieces of information from various sources. Mechanical, electrical, and plumbing trades can also have different symbols and terminology between contractors and design which leads to confusion and errors (Emmitt and Gorse, 2003). Poor information delivery has the potential to have a wide reaching negative effect on project performance. Mourgues and Fischer (2008) argue that communication of project information to the workface is ineffective and can negatively impact quality, safety, and productivity. Rojas (2008) and Schwartzkopf (2004) suggest inefficiencies from design drawings ultimately create increased rework on the project.

Supervisors and foremen then become focused on correcting engineering errors and rework instead of planning future work and focusing on crew performance.

2.3.1. Drawings

Traditionally, two dimensional drawings (commonly referred to as blueprints) have been the means that engineering information is distributed to the practitioners. Drawings are presented in a variety of formats including plan views, elevations, detailed sections, and isometrics. Individual drawings are often scaled, list dimensions, and frequently reference other sheets to help give the reader a representation of the final design intent from all viewpoints.

Figure 2.4 shows a sample plan view for the structural steel for a project. There are a significant amount of callouts that reference other sheets, which requires the worker to flip back and forth between several pages. Complex projects can often have drawing bundles in the several hundred page count with complete set costs measured in thousands of dollars for a single set. These drawings are typically printed in a 24”x36” pack and can be burdensome to use in the field. Similar to the plan view, Figure 2.5 shows an elevation view with many callouts and dimensioned altitudes. Detailed sections, as seen in Figure 2.6, are zoomed in views of particular elements from the drawings. They can be drawn in plan or elevation view, and can also reference other sheets for alternate views or detailed callouts. The drawing type that best attempts to incorporate a three dimensional view is the isometric drawing (see Figure 2.7). Isometric drawings are orientated on a 45 degree, 90 degree, and 45 degree coordinate system that give the reader the optimum view for three dimensions. These are often used for the mechanical, electrical, and plumbing (MEP) trades to give them an idea of the orientation and coordination of their respective systems. They allow for spatial representation and are often referenced to determine the type of bend required for the pipe run. While it does utilize a 3D interface and decreases the amount of reference sheets necessary, the isometric drawings still have some limitations in the information that they can carry.

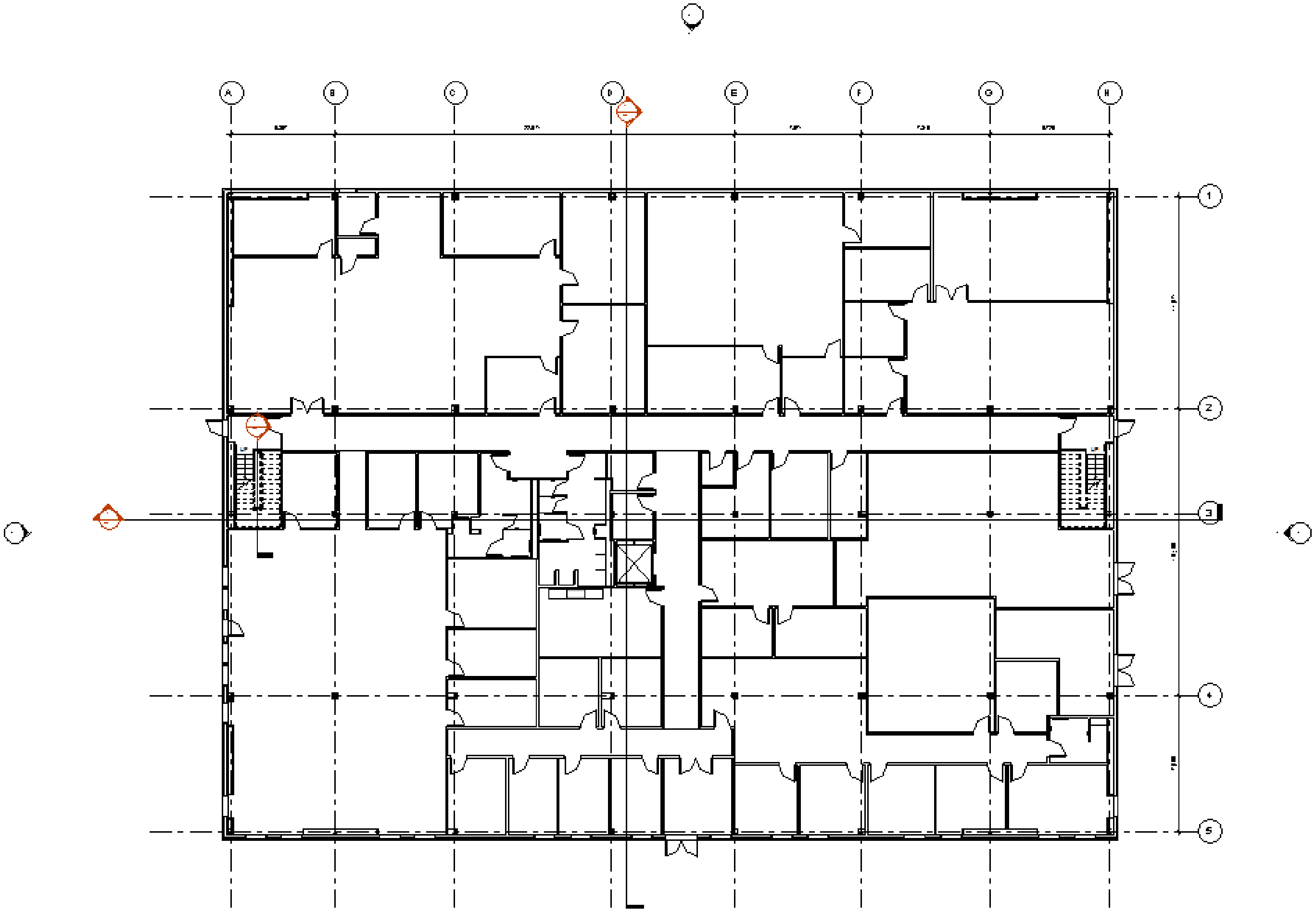

Figure 2.4 Scaled sample plan view of a project (Standard office project Revit file from National Building Information Model Standard)

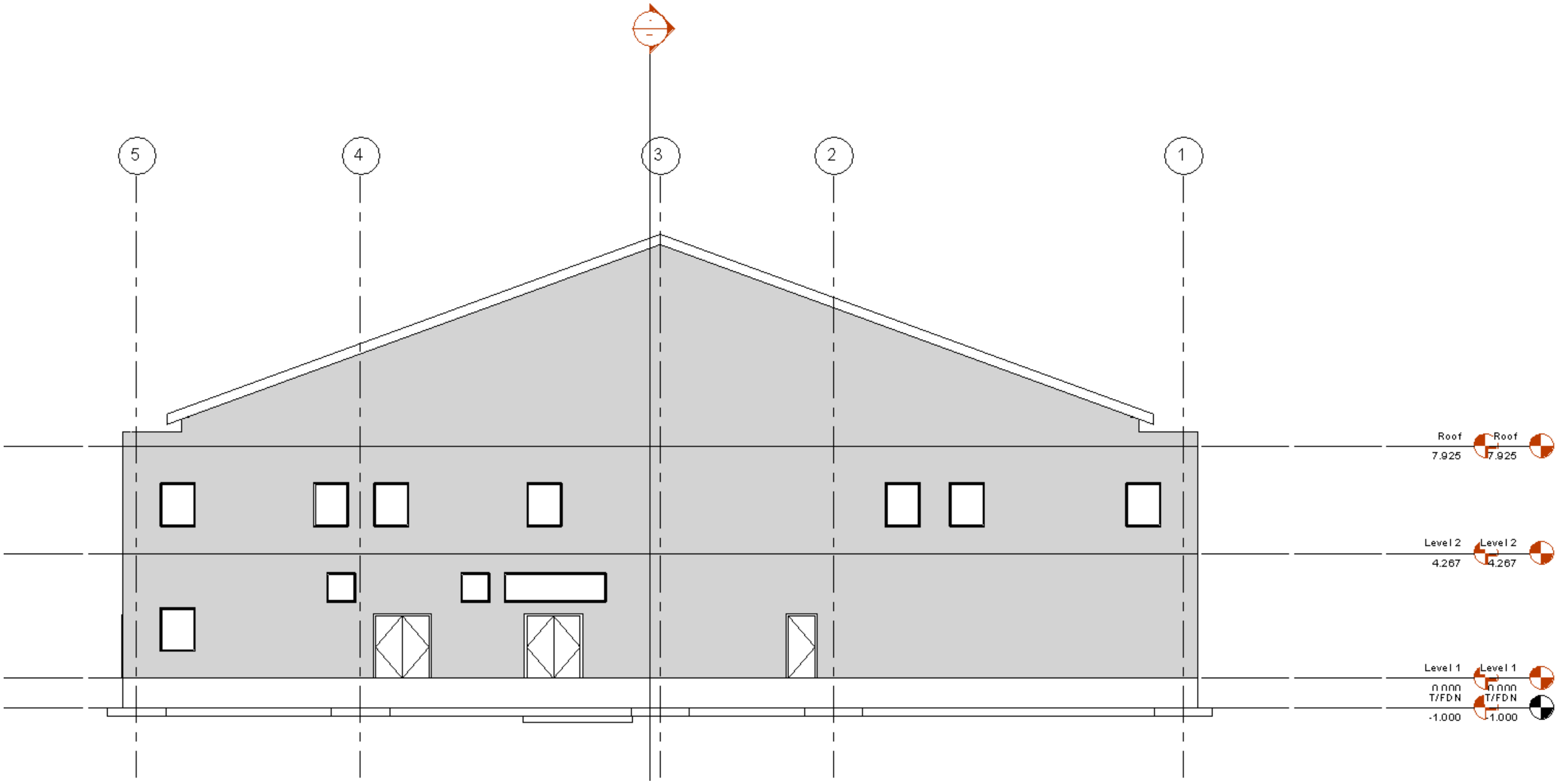

Figure 2.5 Scaled sample elevation view of a project (Standard office project Revit file from National Building Information Model Standard)

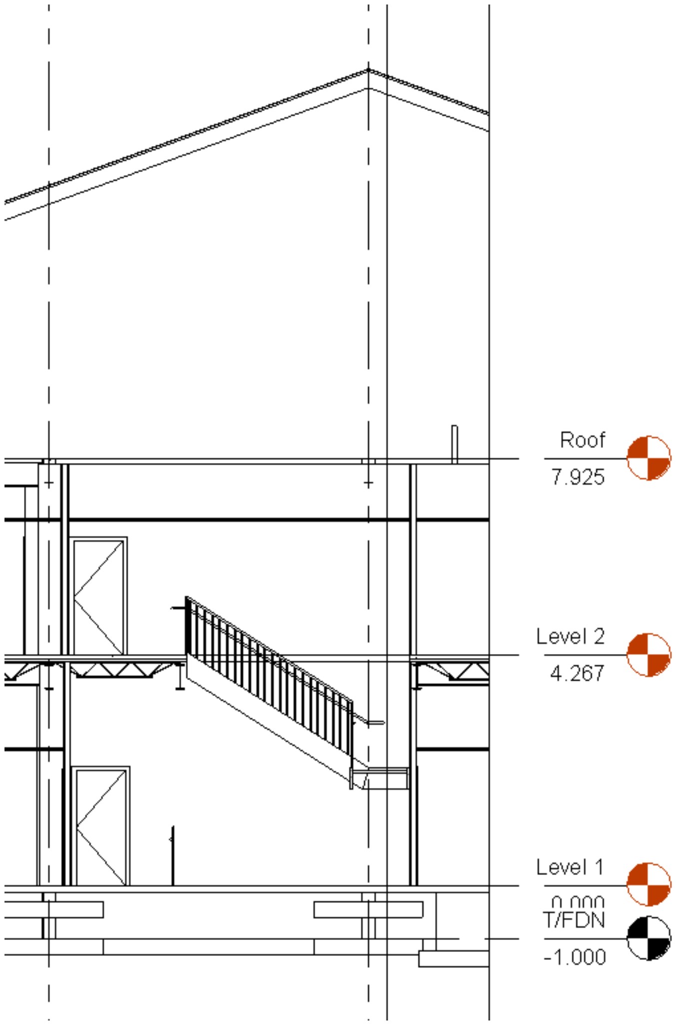

Figure 2.6 Scaled sample detailed section of a project (Standard office project Revit file from National Building Information Model Standard)

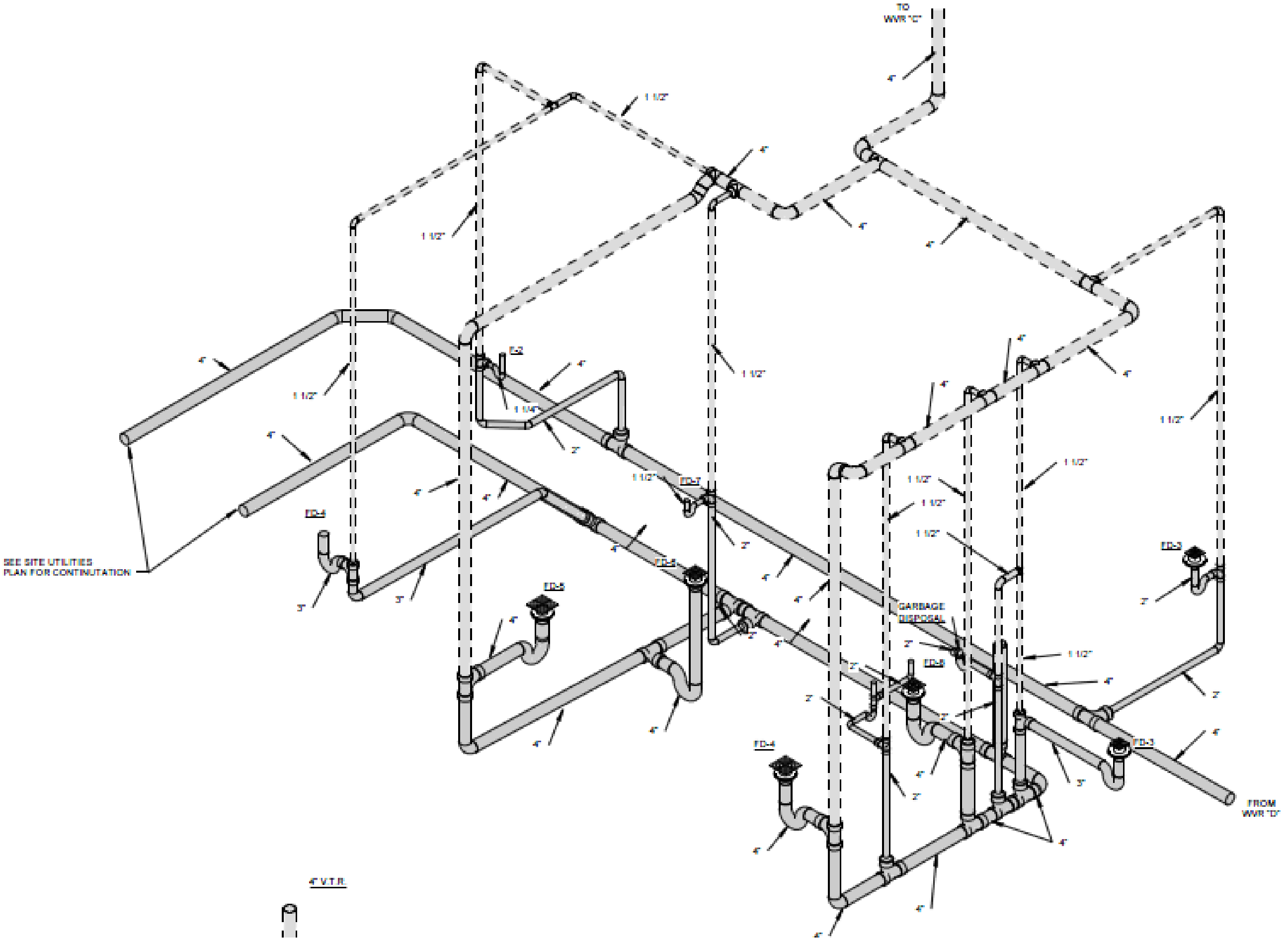

Figure 2.7 Scaled sample isometric view of a project (Standard office project Revit file from National Building Information Model Standard)

All of these drawing views can be combined to create the full mental image necessary to perform work. By referencing many sheets, workers can easily misremember or forget items that they have previously seen. There is also an opportunity for workers to reference the wrong drawing detail. Drawings are often used in combination with verbal work instructions, which can be inconsistent and even more so misunderstood. Mourgues and Fischer (2008) describe the process sequentially. First, the foreman instructs the crew to perform task X in location Y, and the crew consents. They must then reference all of the proper documentation (e.g. drawings and specifications). When they arrive at the workface, they may be faced with questions concerning equipment, tools, materials, procedures, and even questions about the actual drawings. Either the crew can decide to perform the task (often incorrectly or insufficiently) or attempt to get the questions answered. The former leads to rework and potentially unsafe conditions, while the later lowers productivity. All of the consequences result in lower worker morale. While 2D drawings have been effective for many years, there may be opportunities to better represent certain details in a 3D physical format.

The previous discussion focuses on errors made by the individuals interpreting information from a flawless design that is easily interpretable. This assumption is not safe to make in the industry. Often, there are errors or omissions in the drawings set that further lead to errors in the field. With errors being made by designers on the front end and the foremen/craft workers on the back end, the potential for major impacts to a project’s performance is evident. Any efforts that can be made to limit errors on either end will have a positive effect on productivity, morale, safety, and communication.

2.3.2. Work Packages

As a means to better deliver information to the practitioners, construction managers and planners have been preparing work packages. Work packaging is considered more of a process than a product that focuses on collaboration between engineering and construction. The Construction Industry Institute (CII) has devoted a research team (RT 272) entitled “Enhanced Work Packaging: Design through Workface Execution” to study current practices in work packaging. The team identified three different work packages that can lead to better project performance with specific information for the end users (see Table 2.1).

Table 2.1 Different work packages and included information (Construction Industry Institute, 2011b)

Work Package Type	Installation Work Package (IWP)	Engineering Work Package (EWP)	Construction Work Package (CWP)
Information Included	Quantity work sheet	Scope of work with document list	Safety requirements
	Safety hazard analysis	Drawings	At least one EWP
	Material safety data sheets (MSDS)	Installation and materials specifications	Schedule
	Drawings	Vendor data	Budget
	Specifications	Bill of materials	Environmental requirements
	Change documents	Line and equipment lists	Quality requirements
	Manufacturer’s installation instructions	Additional pertinent information to support	Special resource requirements
	Model shots		
	Bills of materials		
	Required tools		
	Installation test results forms		
	As-built documentation		
	Inspection checklists		
	Completion verification signatures		

The need for the study focused around the amount of rework due to poor field planning and coordination (Construction Industry Institute, 2011b). While the study implied that work packages improve planning and coordination, it does not attempt to understand practitioner's ability to grasp the fundamental spatial concepts contained in the drawings. Although work packages contain more information than a typical drawing such as schedule and budget details, the same spatial information is displayed in the form of 2D drawings.

The work packaging process is a much needed effort towards re-thinking how engineering information is disseminated. In its current form, work packages attempt to focus the entire project's information into a more reasonable subset of all project data. The studies do not make an attempt to understand exactly what information is needed by certain practitioners (and no more than necessary), and how that information should be presented. This research presents a first step towards targeted information delivery.

2.3.3. Assembly Drawings

A promising 2D alternative to the standard drawing are assembly drawings. Often referred to as the "IKEA model" for information presentation for its similarities to drawings by the popular Swedish furniture company, assembly drawings for construction are adopted from the manufacturing industry (see Figure 2.8). This concept has been developed and studied as a means to improve work instructions (Antifakos et al., 2002, LeFevre and Dixon 1986, Heiser et al., 2003, Agrawal et al., 2003, Smith and Goodman, 1984, and Emmitt and Gorse 2003).

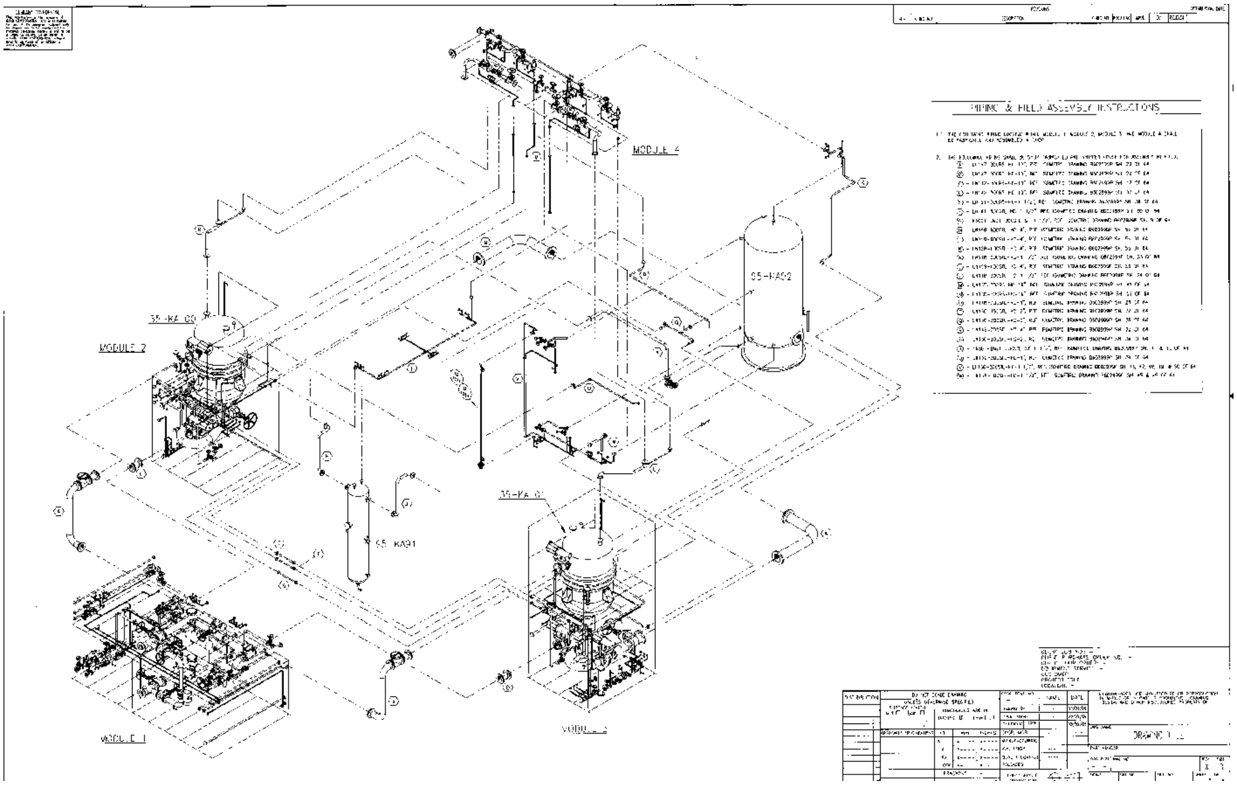

Figure 2.8 Sample assembly drawing

Assembly drawings leverage the field of cognitive psychology to determine the characteristics necessary for effective learning (Dadi and Goodrum, 2011; Antifakos et al., 2002). Heiser et al. (2003) and Agrawala et al. (2003) have defined the following principles as being critical for quality assembly instructions:

- Hierarchy and grouping of parts. The elements of the object to be assembled have a hierarchy of parts and workers tend to desire a group of similar parts be assembled at the same time or in sequence;
- Hierarchy of operations. Workers think of instructions as a hierarchy of tasks. Sub-assemblies are performed at lower levels and are then incorporated into a larger structure at higher levels;

- Step-by-step instructions. Workers like a sequence of instructions rather than one sheet with several tasks detailed;
- Structural and action diagrams. Action diagrams (use guides to show where new parts are assembled to existing) are more preferred over structural diagrams (drawing with all the parts already in their final place);
- Orientation. Maximizing the visibility of all details of the desired object; and
- Visibility. Critical parts must be visible in the diagram.

However, there are some limitations of assembly drawing use in construction. Worker's expertise, the work environment, and task complexity make it difficult to design assembly instructions for general use in the construction industry. In addition, similar to traditional 2D drawings and work packages, spatial information is still presented in a limiting format. This is discussed further in Section 3.2.7.

2.4. Physical Modeling Use and Potential

Physical scale models have been used throughout the construction industry for decades. However, research on their use and benefits is extremely limited. Henderson Jr. (1976) published the most extensive document on scale model use in construction, albeit with a publish date of November 1976. Oglesby et al. (1989) introduced the use of scale models in their well-cited book on productivity in construction; however, the majority of the material is adapted from the Henderson text. This research will refresh the literature and also provide the critical analysis of effective scale model use that previous research lacks.

Scale models are replicas of proposed or ongoing projects and are built to scale to properly display space and how the building elements fit. These models were built in plastic or wood and by the hand of a skilled model maker. Depending on the size of the model, it could take several weeks for the modeler to build the project with the proper level of detail. Some models could be rather large (500 square feet) and difficult to modify when changes arise (Oglesby et al. 1989).

While the use of physical models in the construction phase of a building project is not a new concept, their use has been greatly diminished as computer aided design (CAD) tools have emerged and sophisticated. Designers have instead focused on developing 2D and 3D computer models for use in design, conceptualization, and renderings with efficiency gains from communication as much as 30% (Hobbs, 1999). As the CAD technologies were developed, designers and constructors alike adopted it as a replacement technology to the physical models. Zabilski and Reinschmidt (1996) argue that the industry is moving away from physical modeling and towards CAD technologies for economic reasons. Their arguments are detailed in Table 2.2.

Table 2.2. 3D modeling cost analysis (Zabilski and Reinschmidt, 1996)

3D Modeling Costs (Zabilski and Reinschmidt (1996)	
Reasons Why Costs are Overestimated	**Reasons Why Benefits are Underestimated**
The costs of modeling are added to the costs of the conventional design and construction process, without considering the savings	Estimators are typically conservative
Cost estimators are conservative	Benefits are often intangible and difficult to estimate, resulting in an undervaluation
Managers are unfamiliar with 3D modeling add additional safety factors to the cost estimates	

2.4.1.Drivers for Use of Physical Models

While physical model use has diminished, their advantages still exist today. Years ago, heavy industrial construction projects used the models as a planning and design tools. By modeling the basic layout of the project and its major elements, designers could gain a perspective of the spatial controls in the project. Contractors used the physical models to plan erection and construction sequences, oftentimes for the owner's representative to see and understand (Oglesby et al., 1989; Thabet, 1999). The models were helpful to gauge access space for critical elements to ensure the ability to repair or inspect at a later date. Training operators could often be assisted by a physical model to illustrate the location and layout of the plant. Emmitt and Gorse (2003) find scale models useful for developing designs and testing innovative details prior to production.

Oglesby et al. (1989) presents a brief case study of the use of physical models. As part of pre-construction activities, a company modeled a precast concrete building frame with individual elements. A sample crane was also modeled to scale, and management utilized its reach and swing angle to plan critical lifts and erection sequences. By modeling the project with individual pieces, the constructors were able to plan a fabrication sequence and a laydown yard to coordination with the erection. After studying the plan, the erection subcontractor lowered his initial bid by approximately 50%. There were also time savings due to up front coordination from the erection plan.

While the case study illustrates a specific example where physical models assisted in the construction of the project, there are few other sources of such research. This is often due to difficulty in measuring and recording the benefits of modeling. Oglesby et al. (1989) surveyed managers who concluded that physical models were a useful tool for planning and communications, and that modeling pays for itself easily. However, no direct benefit was quantified. The authors also quote an owner who believes, "If you elect not to model, add from one to two percent to the total field cost and ten percent to the piping cost alone (Oglesby et al., 1989)." Another study estimates that a 25% reduction in labor cost can be realized by minimizing productivity losses on indirect work by implementing a more detailed execution planning strategy (Construction Industry Institute, 2011b). Physical models, as a supportive piece of information delivery, can be a useful portion of the execution planning strategy. Oglesby et al. (1989) found that workers believe models are more easily understood and readable than the "standard sheafs of hundreds of drawings, that superintendents and foremen can plan their work more effectively and more quickly around the model, and that erection sequences are easier to plan."

2.4.2. Additive Manufacturing (3D Printing) for Scale Models

The use of physical models in construction was prevalent historically; however, their current use is greatly diminished. This is discussed in Section 2.4. The expense and inflexibility of model creation along with development of 3D CAD technologies were the main causes behind the fading use of physical scale models. However, 3D printing technologies, a form of additive manufacturing, have developed and advanced to the point where these 3D CAD models can be easily and quickly printed.

There are many companies that have developed 3D printers with similar technologies. The printers work by essentially building up an object with individual thin layers of the material. However, these printers make use of essentially two different types of output materials: ABS plastics or high performance composite starch. ABS (acrylonitrile butadiene styrene) plastic is the common output material for most 3D printers, while the high performance composite starch is the output material for printers by other companies. This line of printers allows for color printing of the models, whereas the ABS printers print in the color of the material mold.

The ABS printers dispense a thin layer of resin using a UV laser, after which it hardens. The build tray drops a small amount to allow a new layer to be added, and that process repeats until completed. The resins form into either a soluble (support material) or insoluble (build material) plastic. The model is finished by a chemical bath that washes off the soluble plastic until only the desired model remains.

The starch printers work in a similar fashion; however, instead of using soluble or insoluble plastics, the printers dispense and bind a layer of white powder. After the printer runs its course, the excess powder must be blown off with a vacuum and small pneumatic hose. Each layer (from 0.004” to 0.03” thick) for either the ABS or starch printer can be completed in approximately 15-30 seconds (The Economist, 2009).

While 3D printing technology has made inroads in manufacturing and medical industries, its use in the construction industry remains limited. There are some barriers to entry in the industry. Without a research or industry effort to study and quantify the benefits of using 3D printers, adoption throughout the industry is fundamentally difficult. In addition, the printers require some training not only in their use, but CAD training to design the model to be printed. There are strict technical requirements in the design and outputting of the CAD files for the prints to be successful such as complete mesh modeling, minimum print thickness, and elimination of degenerate or duplicate mesh faces. However, as the technology matures, construction professionals will begin to see its value and potential. A survey of building professionals perception of information technology (IT) found that mature technologies are better regarded than new technologies (Johnson and Clayton, 1988).

To familiarize with the technologies for 3D printing, the doctoral candidate has worked to develop several building models that are potential prints. In working with the University of Kentucky’s College of Design, the candidate has printed a sample section of a local mixed-use construction project. The sample was printed using an ABS material based printer. A screenshot of the full model file and a blowup of the section is presented in Figure 2.9, while the actual printed output can be seen in Figure 2.10. Figure 2.10 presents an isometric view of the model (11”x9”x9”), as well as two pictures that give a sense of the level of detail capable of the printer. The second image of a plan view shows the thickness of the web on the column, which is about 0.16cm (1/16”). The third image shows the thickness of the hollow bracing, which is about 0.1cm (0.03”) and the smallest feasible thickness of the printer.

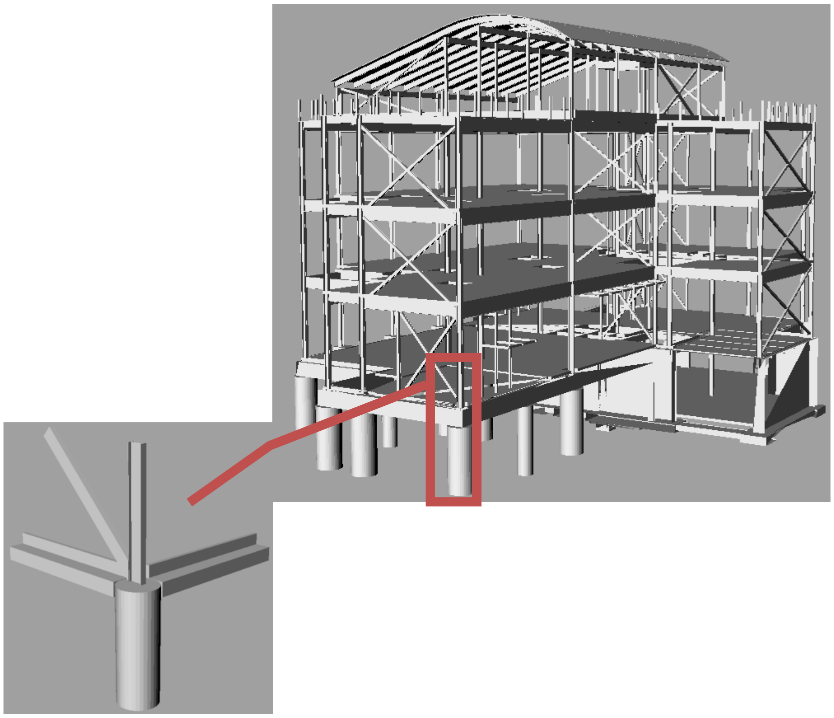

Figure 2.9 Model file used for test printing (Full model shown with section highlight, Wildcat Coal Lodge Project)

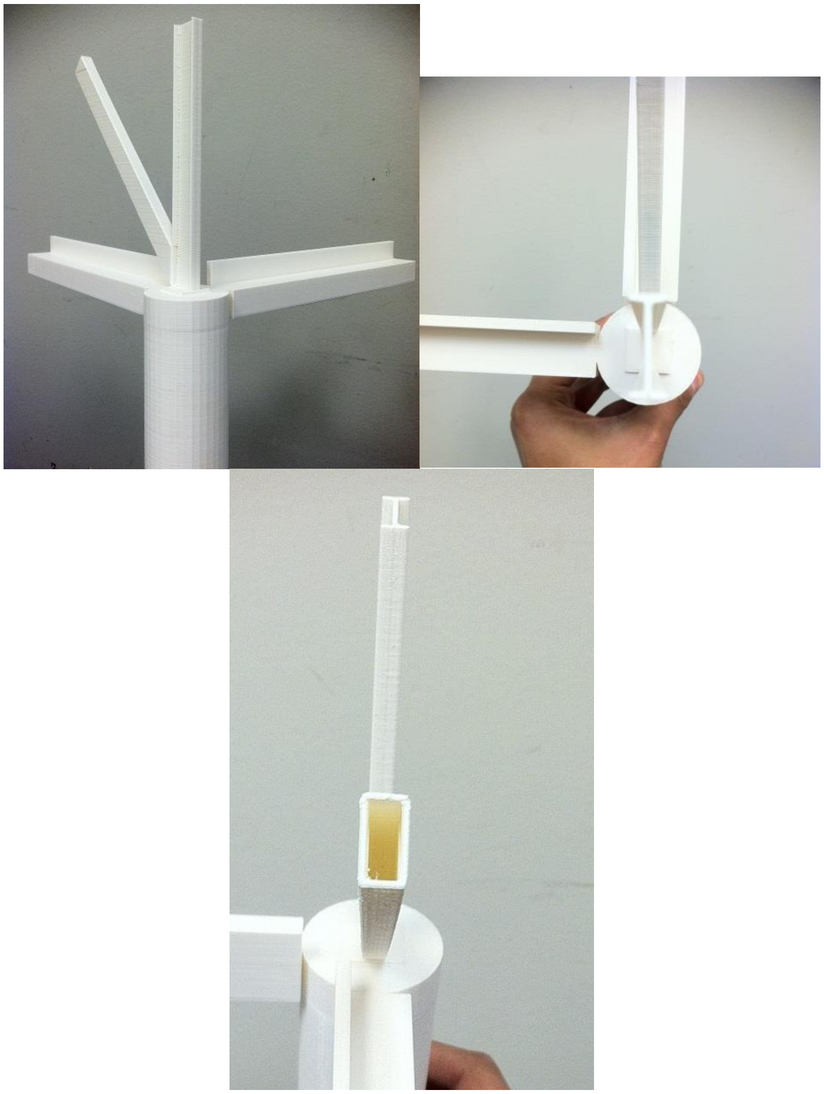

Figure 2.10 Actual printed output of sample section

CHAPTER THREE: COGNITIVE PRINCIPLES IN ENGINEERING INFORMATION PROCESSING

3.1. The Communication Process

One of the main challenges in processing project information is that the design may be well intended, but for a variety of reasons, the message received differs from the original intent. This process of creating a message, disseminating, and then processing essentially describes the well published theory of the linear standard communication process. Many models have been created to describe the process with varying stages, however, the essential elements are outlined in Figure 3.1 (Shannon and Weaver, 1948; Schramm, 1954; and Berlo, 1960).

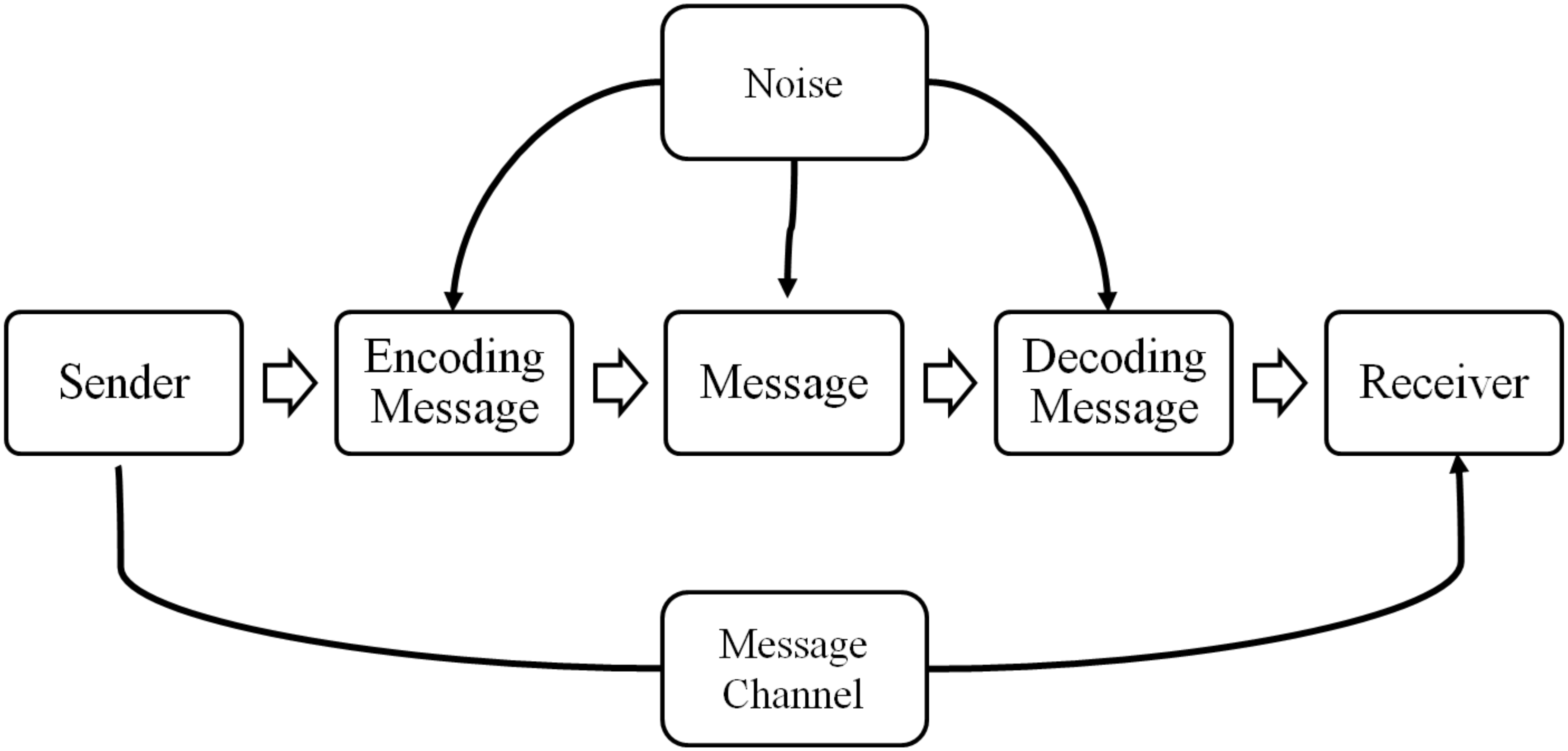

Figure 3.1 Standard Model of Communication (adapted from Shannon and Weaver, 1948; Schramm, 1954; and Berlo, 1960)

In this standard, linear model of communication, the sender must encode their interpretation of the desired end user information. This interpretation is then translated in the message medium, whether it is verbal or non-verbal. In the case of this research, the message is the information delivery format (2D drawings, a 3D model on a computer screen, or a physical scale model). Then the receiver must decode the message into their individual interpretation, where the final message is processed and understood. However, the intermediary steps of encoding the message, the creation of the message, and decoding the message opens the potential to noise that can affect the ultimate outcome of the communication. The message channel is the actual flow of the message, verbal or nonverbal, from the sender to the receiver. In the linear model, there is very little, if any, feedback from the receiver to the sender, where ultimately only a downstream process occurs (Shannon and Weaver, 1948; Schramm, 1954; and Berlo, 1960).

3.1.1.Effective Communication of Engineering Information

The process of delivering engineering information to the construction field is no different than the linear, standard model of the communication process. The sender is the architect or engineer, who encodes the message through experience, education, and standard design codes to a two dimensional drawing. The receiver, or construction project management, foremen, and craft workers, decodes the message in order to create a full mental image of the elements to be constructed, and then plan or execute necessary construction tasks.

Noise occurs, just like any other communication process, significantly on a construction project. The demanding environment can make even the simplest task challenging, as field workers must be mindful of other workers, heavy equipment operations, safety hazards, noise pollution, air pollution, and changing terrains. Due to the difficult work atmosphere, it is important that engineering information be communicated in a way that enhances the worker's ability to encode, remember, and transform the information into useable knowledge (Lohman, 1979).

Construction documents can have a perfect design representation, although unlikely, but still the receiver can misinterpret the information and make errors. An electrical engineer can design a room with properly placed conduit, switches, lights, and outlets, however, an electrical contractor can misinterpret the location of each because they are represented in two dimensional space. If the conduit, switches, lights, and outlets could be represented in three dimensional space, the electrical contractor could gain a quick and easy understanding of the layout of the room and the relative location of the objects and potentially not make those errors. By understanding the decoding strengths and weaknesses of practitioners, design representations can be better presented to improve communication, coordination, and productivity of the practitioners.

3.2. Cognitive Factors for Spatial Processing

When deconstructing a construction project into information for practitioners to process, it is important to design with cognitive principles in mind. A practitioner is often presented with a document containing the designs of several individuals, each with their own terminology and design principles behind it. Useful information may be lost as the end user cannot be expected to obtain the exact message that the sender desires. This leads to confusion and errors in reading the drawings. It is important for work instructions to be clear, concise, complete, correct, meaningful, relevant, accurate, and timely (Emmitt and Gorse, 2003). Therefore, it is important for any method of information delivery to the craft to be representative of cognitive principles that lend to efficient processing of spatial information.

The cognitive concept in processing spatial information is defined as an individual's spatial ability (Carroll, 1993; Lohman, 1979). Spatial ability refers to the ability to generate, retain, and manipulate abstract visual images. For an individual to understand and access a spatial concept, they must "encode, remember, transform, and match spatial stimuli" (Lohman, 1979). The reader reassembles the orthographic display in their mind, which from a 2D perspective, can lead to ambiguities, omissions, and interferences (Zabilski and Reinschmidt, 1996; Rieber, 1995). Several distinguishable factors to measure spatial ability have been previously defined and tested and are discussed in the following paragraph (Carroll, 1993; Heiser et al., 2003; Lohman, 1979; Miyake et al., 2001; O'Malley and Fraser, 2004).

Table 3.1 lists the major spatial factors defined in Carroll (1993), however, these factors are included in other examinations of spatial abilities under similar definitions (Eliot and Smith, 1983; Lohman, 1979; Thurston, 1938; Bechtoldt, 1947; Pemberton, 1952; and Jeffrey, 1957). The factors listed in Table 3.1 are defined as the characteristics inherent in an individual's spatial processing ability. Therefore models of spatial information should seek to make these factors easily comprehendible by the user. The following subsections will outline tests that have been developed and identified with each factor.

Table 3.1. Major spatial factors summarized from Carroll (1993)

Factor Name	General Definition
Visualization	Ability to perceive multiple patterns accurately and evaluate one with the others
Spatial Orientation	Ability to understand various orientations in which a pattern is presented
Flexibility of Closure	Manipulation of two configurations at the same time or in succession
Spatial Relations	Ability to understand abstract movements in 3-dimensional space or manipulate items in an imagination
Spatial Scanning	The speed in which an individual visually explores a wide or complicated spatial field
Perceptual Speed	Speed in finding a given configuration within a system of distracting elements
Serial Integration	Ability to notice and identify a pattern when elements are presented at a high rate
Closure Speed	Ability to merge disconnected, vague, and visual elements into a logical whole
Visual Memory	Ability to form and retain a mental image or representation of a space that does not represent an easily identifiable object
Kinesthetic	Ability to understand spatial concepts by manifesting in and moving in the actual environment

While all of the above factors play a role in determining one's spatial ability, Carroll (1993) determined that five have a more significant impact than the others. These are noted as strong indicators for visual perception and are visualization, spatial relations/orientation, closure speed, flexibility of closure, and perceptual speed. The following subsections will outline these factors in more detail and provide reference to tests acknowledged by the Educational Testing Service (ETS) as reliable evaluations of the factors. The ETS tests were published and discussed in French, Ekstrom, and Price (1963), Ekstrom, French, and Harmon (1976), and Ekstrom (1979).

3.2.1. Visualization

Visualization has been defined by French (1951) as the "ability to understand imaginary movements in a 3D space or the ability to manipulate objects in imagination". There are several tests used to evaluate the visualization capabilities including the Form Board Test, Paper Folding Test, and Surface Development Test as given in the 1963 ETS factor kit (French, Ekstrom, and Price, 1963).

- The form board test presents subjects with five shaded drawings and a figure that is presented to the subjects. Some or all of the drawings pieced together create the desired figure. The subjects are asked to indicate which drawings fit together to form the figure.
- The paper folding test presents subjects with a square piece of paper that is then folded in two or three steps. A hole is then punched into the folded paper. Subjects are presented with five drawings, and they are asked to select the drawing that illustrates what the paper will look like when it is unfolded.

- The surface development test presents subjects with a drawing of a solid to be created. A diagram showing how a piece of paper might be cut and folded to create the solid is also given. This diagram has numbered edges and dotted lines for labeling. The drawing also has lettered edges, and the subjects must correctly match the numbered edges to the same lettered edges.

These tests all measure an individual’s ability to encode and modify a three-dimensional space in their imagination. The concept focuses on understanding a spatial form in order to relate it with another spatial form that requires rotating the initial form. The test do not have a concern for the speed in answering, rather only the accuracy in the responses. These would prove to be difficult to recreate specifically with a building model and drawings, however, that is not necessarily the intent of this research. Testing an individual’s ability to visualize space, modify it, and then recreate a likeness is the essence for this factor.

3.2.2. Spatial Relations/Orientation

Spatial relations are generally defined as the ability to recognize and understand patterns and maintain orientation of objects in a space. The tests identified by ETS as significant for understanding spatial relations are the card rotations test and the cube comparisons test. The tests are to be speeded, as too much time allows subjects to answer beyond the desired testing ability of rotating the images mentally.

- The card rotations test (see Figure 3.2) depicts several orientations of shapes of similar design. The object is to correctly identify the ones that match the original shape given. Essentially the options are either rotated (accepted as the original shape) or flip and/or rotated (not the original shape).

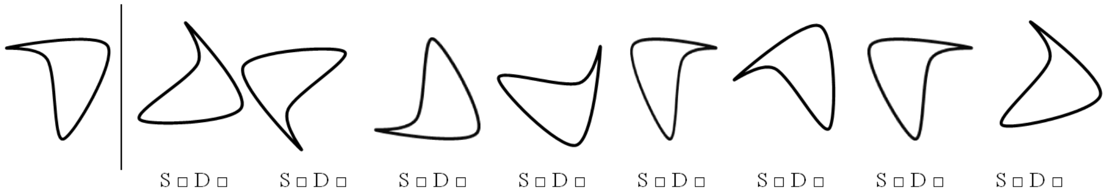

Figure 3.2 Card Rotations Test (adapted from Ekstrom, French, and Harman, 1976)

- The cube comparisons test (see Figure 3.3**Figure**) presents two cubes with labeling of each face. Assuming that no two faces are labeled the same, the subject must identify whether the cubes could be the same or must be different.

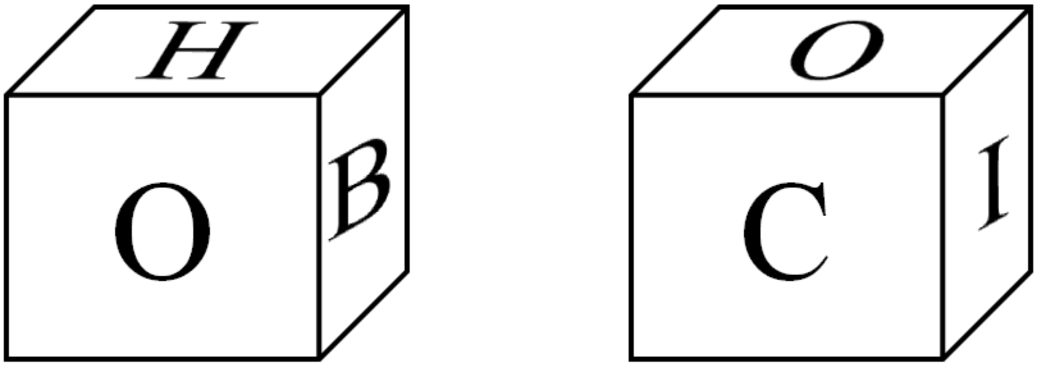

Figure 3.3 Cube Comparisons Test (Adapted from Ekstrom, French, and Harman, 1976)

3.2.3. Closure Speed

Closure speed is defined as the ability to construct a known configuration from an obstructed version of the configuration. Carroll (1974) believes closure speed "requires a search of a long-term memory visual-representational memory store for a match for a partially degraded stimulus cue." The accepted tests for closure speed are the Gestalt completion test, the concealed words test, and snowy pictures test.

- The Gestalt completion test presents black blotches representative of an object. The subject is asked to describe the object as specifically as possible.

- The concealed words test presents the subjects with words that have parts of letters missing. The subjects must then write out the complete word that they are able to piece together.
- The snowy pictures test asks the subjects to identify objects from a “snowy” spatter in the background.

3.2.4. Flexibility of Closure

Flexibility of closure is a measure of an individual’s ability to find a given configuration in a convoluted spatial environment. According to Carroll (1974), this ability is founded in short term memory where a figure is dislodged from other visual stimuli. The marker tests for this ability are the hidden figures test, the hidden patterns test, and the copying test.

- The hidden figures test requires subjects to identify which figure from a selection of five is represented in a diagram containing many shapes.
- The hidden patterns test measures how fast an individual can identify a figure that is hidden amongst other similar configurations. The presented figure cannot be changed in the given responses.
- The copying test investigates the subject’s ability to remember a pattern and then later identify it in a set of square dots. The pattern must begin with the circled dot and intersect at dots where the pattern turns.

3.2.5. Perceptual Speed

Perceptual speed measures the ability to quickly compare figures, identify symbols, and then conduct simple tasks regarding visual perception. Differences in individual ability can be attributed to perceptual fluency, decision speed, and immediate perceptual memory (Ekstrom, French, and Harman, 1976). The market tests for this ability are speeded and are the finding 'A's test, number comparison test, and identical pictures test.

- The finding 'A's test lists five columns of several words in each. The subjects must identify the five words in each column that contain an 'A' as quickly as possible.
- The number comparison test asks subjects to compare two numbers and mark the set if they are different.
- The identical pictures test presents a figure to the subjects and asks them to identify which figure in a lineup of five matches the original object.

While all of these tests can be applied to determine an individual's spatial ability, the ability of concern for this study is the spatial rotations or orientation ability. The Card Rotations and Cube Comparisons tests provide a measurement of the ability to recognize patterns in two and three dimensions and then complete a rotation task. That is the essential mental function that is tested in the experiment that will be discussed later. For a look at how these cognitive factors can and will be applied to the study, see the discussion in Section 4.2.4.

3.2.6. Human Factors Design in Engineering Studies

Beyond the cognitive principles that are represented among the population, a study of spatial understanding must be effectively designed. As with any design for use by end consumers, the concept must be effectively translated for mass comprehension. That is the principle behind human factors design, and it is a heavily researched and published field within psychology. However, little has been researched and written when it comes to communicating through visualizations. Tory and Moller (2002) suggest that "more attention should be paid to users who must view and manipulate the data because how humans perceive, think about, and interact with images will affect their understanding of information presented visually." Further, the authors suggest that rapid prototyping, while not widely adopted, could improve methodologies in designing visualization tools and interfaces. If these systems are not effectively designed, their impact will not be fully realized, and certain users will have difficulty interacting and understanding them. Users can perceive information in many ways due to a variety of individual factors including lighting conditions, visual acuity, surrounding items, color scales, culture, and previous experience (Tory and Moller, 2002). Many of these factors are tested and evaluated through the cognitive tests discussed in Section 3.2.

While no studies have been identified that studied engineering drawing displays with human factors designs, there has been work in relating human factors designs to engineering process monitoring. The driver for these studies has been to maintain a high level of situational awareness for the operators. Tharanathan et al. (2010) defines situation awareness as "a person's perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future." Poor situational awareness has been attributed as the cause for industrial accidents and aviation incidents (Tharanathan et al., 2010). The human factors engineering studies follow a similar methodology and research question that is proposed in this document.

3.2.7. Weaknesses of 2D Presentations of 3D Information in Human Factors

Non-engineering related fields have conducted human factors studies relating to 2D versus 3D displays. Hypotheses, as expected, are that 3D displays provide greater understanding of spatial information than their two dimensional counterparts. Three dimensional displays are thought to be more natural and provide greater spatial flexibility, which increases the basic understanding for the end user (Cockburn and McKenzie, 2002; St. John et al., 2001; Hickox and Wickens, 1999). Weaknesses of two dimensional interfaces in presenting a 3D object are:

- Lack of depth cues prevents user from understanding location of objects within the viewing plane. This is referred to as projective ambiguity or line-of-sight ambiguity (Sedgwick, 1986; Boyer and Wickens, 1994).
- Space is nonlinearly distorted (in distances and angles) when magnification or translations occur.
- The projection of items angled toward the line of sight shortens the appearance of the actual distance. This is known as foreshortening (Sedgwick, 1986).

However, other studies have found that 2D displays are more desirable depending on the type of information that is to be relayed (St. John et al., 2001; Boyer and Wickens, 1994). St. John et al. (2001) found that 2D displays are ideal for judging relative positions, while not as useful for shape understanding. Boyer and Wickens (1994) found that 2D views eliminate projective ambiguity and can have greater situational awareness outcomes. The conclusions essentially find that 3D views are useful for shape understanding but restricts the ability to relate position of objects due to ambiguities and distortions. It can be concluded that physical models would eliminate the shortcomings of 3D interfaces and provide the same benefits.

3.3. Mental Workload

A critical cognitive component to the design of information delivery is in the mental workload requirements. Assuming that everyone has a fixed cognitive capacity, mental workload is the amount of mental resource required compared to the total resources available to that person (Carswell et al., 2005). An effective method of information delivery should reduce the mental workload requirements while also performing the desired task acceptably. Typically, this involves reducing the amount of time the user must retain the information in their working memory and reduce the irrelevant, distracting mental operations that may occur. This, in turn, increases the situational awareness of the user. Tharanathan et al. (2010) defines situation awareness as "a person's perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future." Poor situational awareness has been attributed as the cause for industrial accidents and aviation incidents (Tharanathan et al., 2010). Situational awareness has been frequently studied in aviation and other display-oriented fields (Ellis et al., 1987, Naiker et al., 1998).

3.3.1. Measurement of Mental Workload

Much research in cognitive designs has identified three classes of mental workload metrics used to evaluate the outcome of the study. The classes are physiologic, secondary task, and subjective measures (Carswell et al., 2005). Physiologic measures use indirect measures of mental workload by studying ocular and cardiac responses.

These physiologic responses have a relationship with cognitive activity in the brain. Increased cognitive activity has been found to result in small increases in pupil dilation, slowing blinking patterns, more consistent heart rates, and heightened heart rates (Carswell et al., 2005). Secondary task measures look to identify the remainder of the mental workload, which is not occupied by performing the desired task. These secondary tasks are developed for certain applications such as aviation and high-demand environments. For this study, objective and subjective measures are used as they are readily available, universally accepted, nonintrusive, and easy to administer.

One of the most widely used standardized subjective measures of mental workload is the National Aeronautics and Space Administration Task Load Index (NASA-TLX) (Hart and Staveland, 1988). The administration of this tool to measure mental workload has been used in over 1,200 studies since its inception (Hart, 2006). Although its use is widespread internationally, its use within the construction industry has been limited. A review of available construction literature found only one reference to the tool in Mitropoulos and Memarian (2012). Mitropoulos and Memarian (2012) investigated task demands in masonry work using the NASA-TLX to identify factors affecting activity performance and propose strategies to improve performance. Carswell et al. (2005) describe the NASA-TLX as “multidimensional measures that require respondents to make ratings. The individual scales may be used for diagnostic purposes, and a composite workload measure can be obtained by summarizing across scales.” The examination rates responses in mental demand, physical demand, temporal demand, effort, performance, and frustration.

The advantages of a subjective measure are their widespread acceptance and use as well as the ability to easily administer and interpret the results. However, there are drawbacks to current subjective measures. The subjects must self-evaluate their performance and their cognitive capacity. When responses are obtained verbally, research has shown that subjects tend to respond from their working memory and not their mental workload. Working memory is the active portion of memory that is limited in capacity and retention (Carswell et al., 2005). Response bias could also factor into the results if the subjects are stakeholders in the study. For instance, if conducting this study with a veteran journeyman electrician, he or she may be inclined to prefer the traditional drawing set that has been traditionally used.

The objective measures that were used are time to completion of the task and a five-minute rating for monitoring of rework occurrences. Time to completion of the task for subjects provided a look into the information delivery formats that lend to quicker task completion. The five-minute rating yielded percent of time spent on non-direct work activities, or activities resulting in rework. To conduct a five-minute rating, the researcher prepared a time sheet broken down into subsets of time and then columns for notation of the activity classification. The classification categories were direct work, indirect work, rework, and delay due to rework. Direct work was defined as any physical building of the model towards the final product. Indirect work was defined as any activities performed towards the end result that is not physically building the model. This includes time getting familiar with the building elements, and manipulating and processing the information delivery format. Rework included any disassembling or reassembling of a previously built portion of the model. Finally, delay due to rework included time spent reprocessing the information delivery medium after rework occurs. See section 4.2.3 for further discussion.

CHAPTER FOUR: METHODOLOGY

4.1. Assessment Strategy

To evaluate the assessment strategy for the dissertation, it is important to focus on the primary and secondary objectives of the study. The primary objective of this research is to evaluate the effects of different mediums on the human cognitive interpretation of engineering information. Secondary objectives include:

1. Identify the cognitive principles behind spatial information processing;
2. Identify the uses of the different information mediums available for construction practitioners; and
3. Identify the cognitive traits that are best served by different mediums.

The ability to evaluate cognitive abilities of practitioners in using various information delivery formats requires defined performance metrics. In a discussion of construction communication deliverables, Emmitt and Gorse (2003) suggest that information formats must yield quick, simple, and easily interpretable results. Using those guidelines along with the cognitive principles and measures previously discussed, a series of evaluations have been created for assessment.

4.1.1. Cognitive Task

The main portion of the experiment is a building task using scale model elements to recreate a structure based on given information. The basis of design must be simple enough to solely capture the cognitive aspects of spatial information processing, yet complex enough to where there is difficulty and mistakes can be made. The structure design was created through a standard set of two dimensional construction drawings (blueprints), a three dimensional computer aided design (CAD) model, and a physical model created by a three dimensional printer from the CAD model. Subjects, while timed, are given one of the information formats and then asked to build it with the model set. Samples of the 2D drawings are illustrated in Figures 4.1, 4.2, and 4.3. The full set of drawings for the 2D set can be seen in Appendix A. The 3D CAD model is pictured in Figures 4.4, and 4.5. Finally, the physical model can be seen in Figures 4.6, 4.7, and 4.8. Figures 4.9 and 4.10 show the building elements before and after model creation respectively.

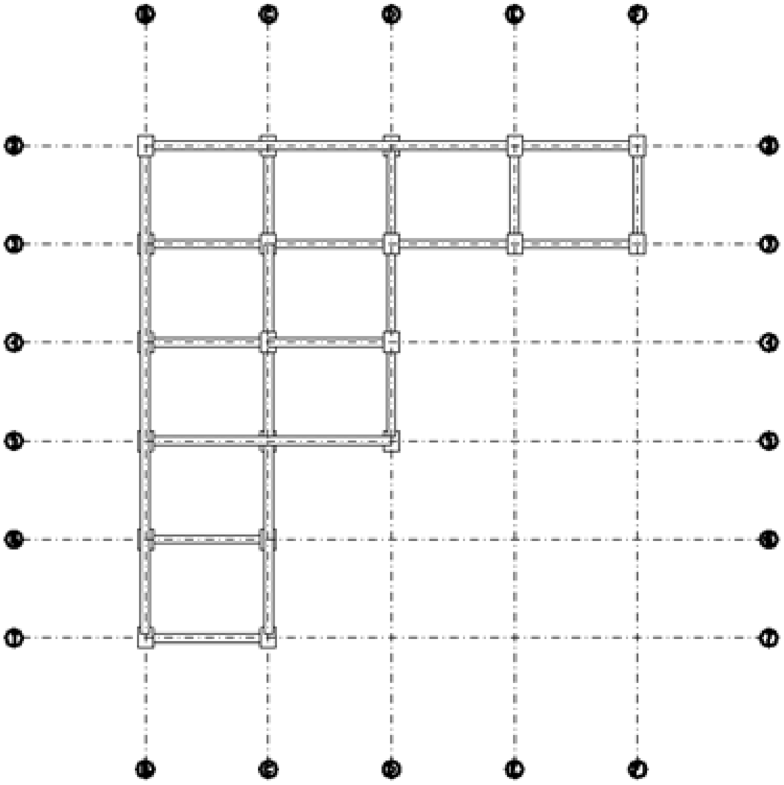

Figure 4.1 2D plan view of experiment model

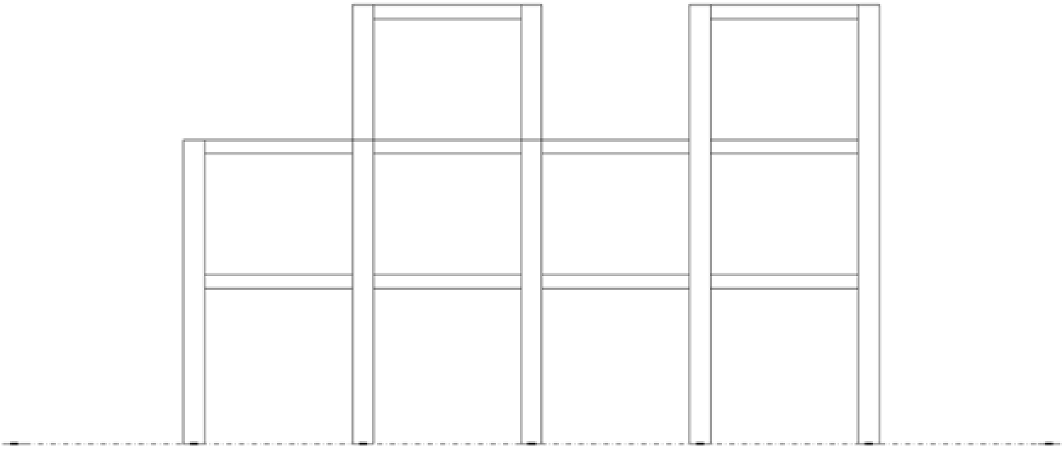

Figure 4.2 2D elevation view of experiment model

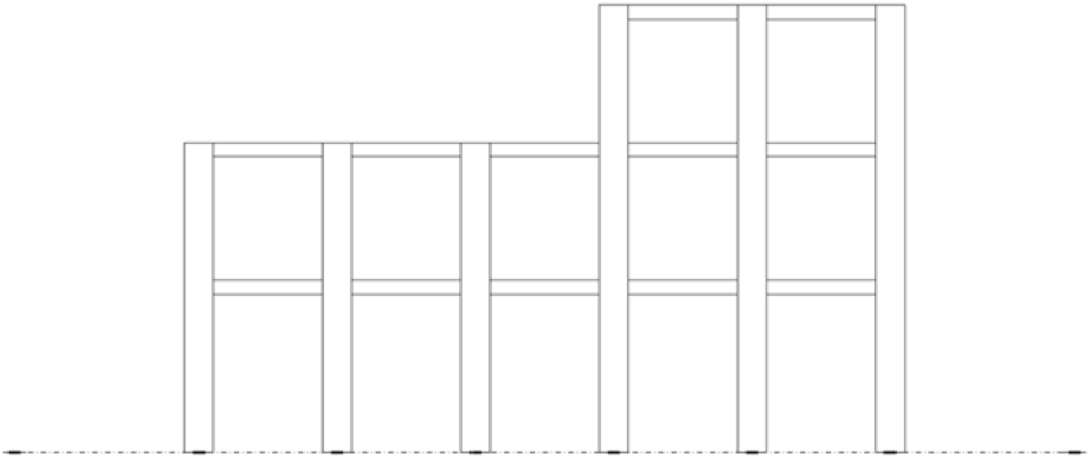

Figure 4.3 2D elevation view of experiment model

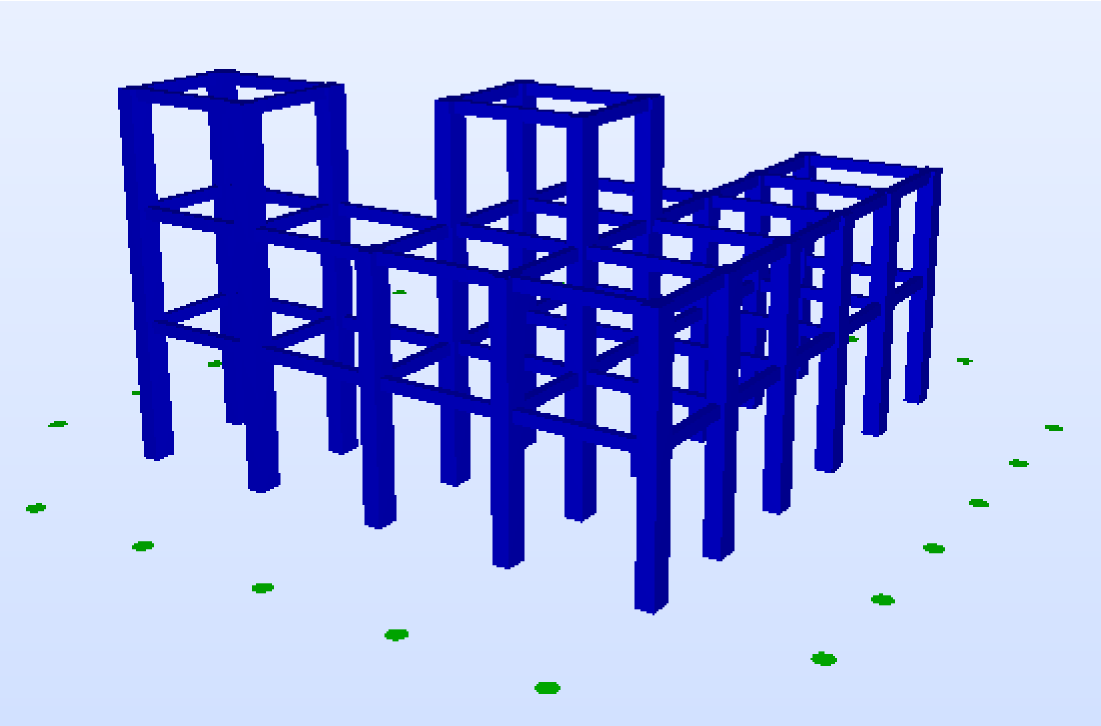

Figure 4.4 3D computer model isometric view

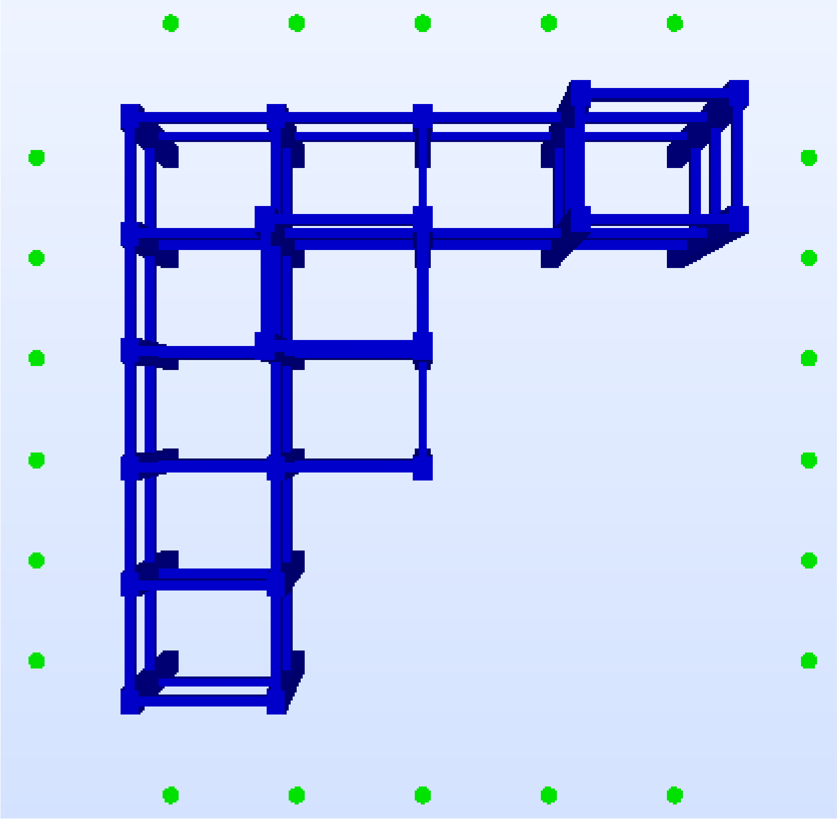

Figure 4.5 3D computer model top view

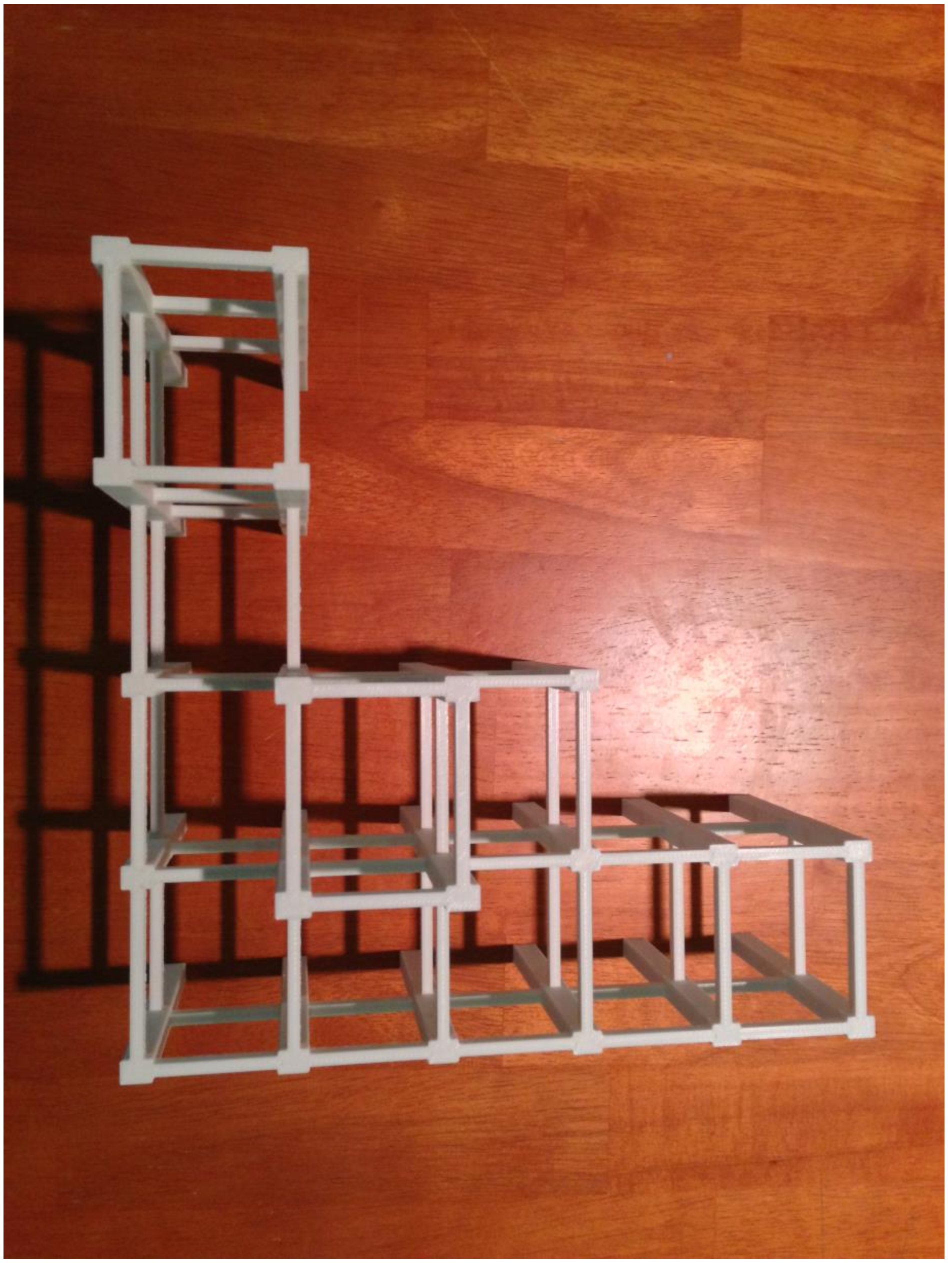

Figure 4.6 3D printed model top view

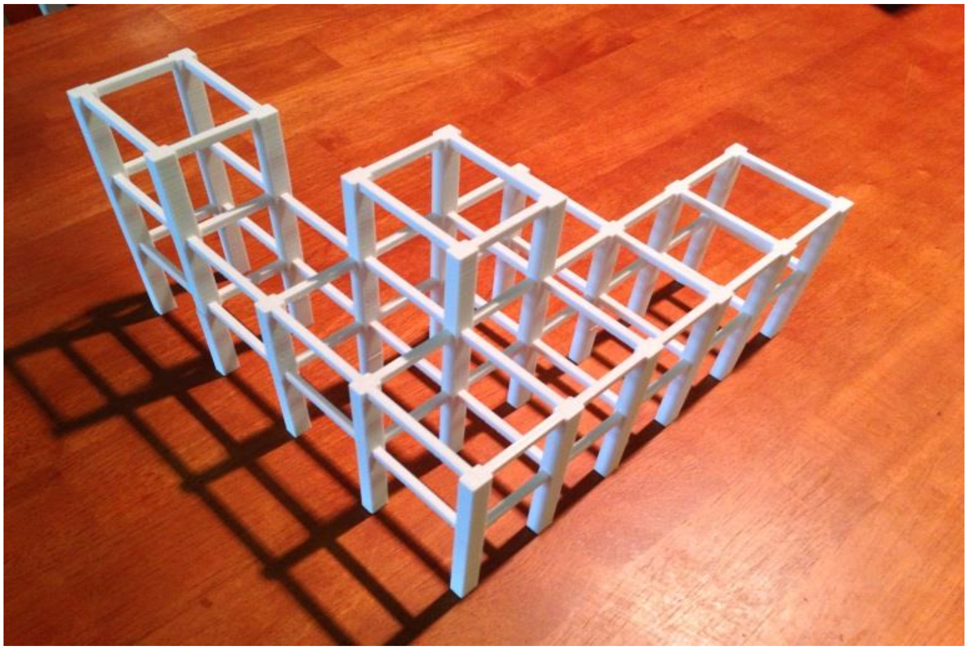

Figure 4.7 3D printed model isometric view

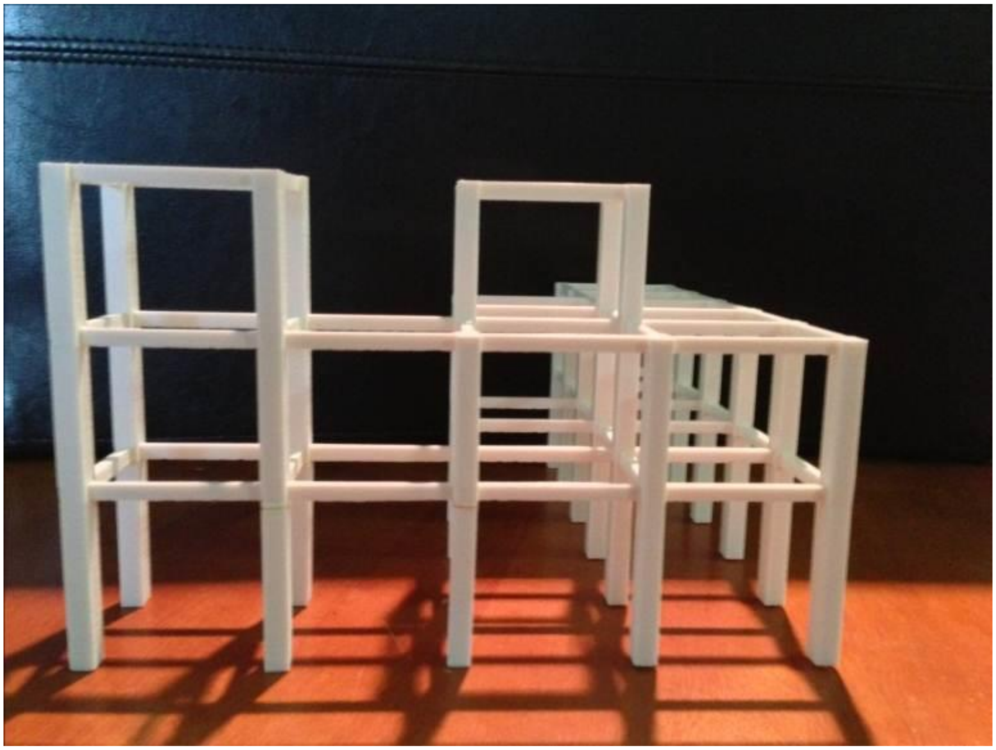

Figure 4.8 3D printed model front view

Figure 4.9 Scale model building elements disassembled

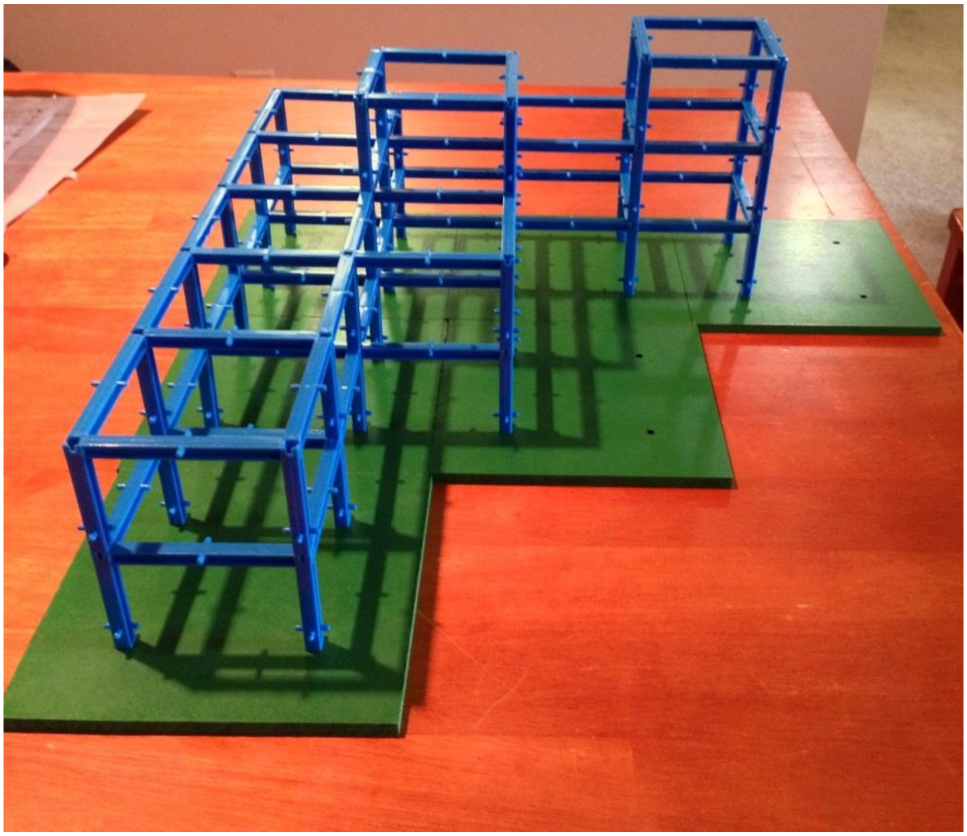

Figure 4.10 Scale model building elements appropriately assembled

The above structure was designed in conjunction with the dissertation committee to represent a simple, yet complex design to measure cognitive abilities with the formats. It is simple in nature, as it is represented in three directions at right angles without distracting elements. Yet it is complex in that one wing extends out further than the other and the third floor towers can be deceiving in certain representations. For instance in the 2D elevation views of Figure 4.2 and 4.3, the third floor tower placements cannot be determined due to lack of depth cues. The complexity of the structure allowed for the occurrence of errors which can be an indicator into which format better represents spatial design.

The program used to create the 3D computer model was Bentley's Structural Modeler. This is a building information modeling (BIM) software that allows for easy build up of structural elements whether it be steel, concrete, or timber. However, this software package has a complex user interface with numerous icons and options, making it undesirable for use in the experiment process. The researcher selected Solibri Model Viewer as the software for use in the task completion. Solibri Model Viewer has a simpler user interface with limited functionality. In the brief tutorial given to the study participants, there were three main function used to manipulate the model; zoom, rotate, and pan. This eliminated potential extraneous actions and focused strictly on the presentation of the model instead of learning new software functions.

The physical model was printed with the assistance of the University of Kentucky's College of Design Workshop and Digital Fabrication laboratory. The model was converted from Bentley's Structural Modeler software into Rhino 5 for modifications that made the model capable of 3D printing. It was printed in ABS (acrylonitrile butadiene styrene) plastic with a Dimension 1200es 3D printer.

Modeling elements needed to be simple, easy to use, and of similar structure to the desired building model. They needed to be a set of beams and columns with simple connections, so as to not be an impediment to task completion. After evaluating several options, the researcher selected the Tekton Tower Girder and Panel Building Set by Bridge Street Toys. It met all of the necessary criteria and did not prove to be a barrier to subject use when completing the building tasks.

Referencing previous discussion, the defined measure of effective information delivery is a format that is quick, simple, and easily interpretable. The measures taken from the experiment to define performance of each format are described in the following sections.

4.1.2. Sample Groups

Two main sample groups were recruited and tested for the study, practitioners and students. Practitioners were recruited to provide a sample of individuals that regularly use design and construction drawings for the purposes of field installation of the final design intent. The subjects from this sample group were recruited from regional engineering and construction firms with a range of experience from approximately one year to over thirty years. Subjects were attracted by entering their name in a drawing for a gift card to a home improvement store. This was received positively by the market and allowed for the participation of 20 subjects.

In addition, undergraduate and graduate students declared as civil engineering majors at the University of Kentucky were also recruited to provide a comparison sample to the practitioners. Students are likely to be more comfortable in a virtual environment than the practitioners and less likely to be more comfortable using 2D drawings than practitioners that use them frequently. This comparison could illustrate the effect that expertise and frequent of use has on the ability to cognitively interpret spatial information. The principle investigator (PI) spoke to and contacted through e-mail several courses in civil engineering asking for participants. Further, advertisements or flyers were placed throughout the Oliver H. Raymond building, the main civil engineering building, on the campus of the University of Kentucky. Participation of this sample group proved to be slightly more difficult than expected, as the PI was unable to recruit students in the class that he taught due to Institutional Review Board (IRB) regulations. In the end, eleven students responded to the requests and participated in the study.

Of the eleven student participants, six had recent field experience or were currently employed as an industry professional. This allowed for inclusion into both samples, when comparing results separately. This brings the student sample size to 11 and practitioner sample size to 26. When combined to study all subjects, the total sample size is 30, 11 currently students and 19 currently employed practitioners. More details about the sample demographics are contained in Table 4.1.

Table 4.1 Sample Demographics

Demographics	Students	Practitioners
Number	11	26
Age Range	21-39	27-62
Number of Engineering Course Hours	9-190	N/A
Years of Experience	N/A	1-33
Classification/Position Titles	Undergraduate Graduate	Carpenter Foreman Laborer Foreman Electrical Foreman Mechanical Foreman Project Engineer Design Engineer

4.2. Objective Outcome Measures

Several objective outcome measures were taken during completion of the test to help quantify results. These include a demographic questionnaire, time to complete the building task, a five minute rating analysis, and spatial orientation ability testing. Each one of these measures will help describe the dynamics occurring during the assessment and to help explain results. The description and methods for each objective measure is explained in the following sections.

4.2.1. Demographic Information

A standard demographic questionnaire helps provide descriptive data of the sample. The following information is queried on the questionnaire:

- Age;
- Gender;
- Current Occupation (Undergraduate Student, Graduate Student, or Industry);
- Years of Field Experience;
- Frequency in Referencing Construction Drawings (five point Likert scale); and
- Number of coursework hours completed (for students only)

Each line of data from the demographic sheet will help describe any experience bias that influenced the results of the experiment. A hypothesis for this data would be that subjects with greater experience in the industry and with using drawings would perform better with the two dimensional drawings than others would. A sample form of the demographic questionnaire can be found in Appendix B.

4.2.2. Time to Completion

Time to complete the experiment is a critical indicator of performance. If one format takes longer for subjects to interpret the presented information, it increases the cognitive demand of the format as well as decreases overall productivity.

In a construction project environment, time is one of many critical pressures and demands felt by all field workers. Spending excessive time reading and interpreting information can be a significant source of waste and decreased productivity (Oglesby, 1989; Hobbs, 1999; Mourgues and Fischer, 2008).

In the context of this experiment, the subjects are instructed that the exercise will be timed. The subjects are instructed pre-test that a timer will be started when the information format is presented to them, and that they are to stop the timer when the model is completely built. This is the time that is recorded for analysis purposes.

4.2.3. Five Minute Rating

Five-minute rating analyses have been performed on many construction field projects to "create awareness on the part of management of delay in a job and indicate its order of magnitude, measure the effectiveness of a crew, and indicate where more thorough, detailed observations or planning could result in savings" (Oglesby et al., 1989). For this experiment, a five-minute rating yielded the percent of the task time that was spent on direct or effective work and on non-effective work or rework. The percentage can be applied to the overall time to completion to give the amount of time spent on each activity category. The data yields effective work percentages of each information delivery format. To conduct a five-minute rating, a time sheet was prepared and divided into subsets of time and then columns for notation of the activity classification. The classification categories are direct work, indirect work, rework, and delay due to rework. Direct work is defined as any physical building of the model towards the final product. Indirect work is defined as any activities performed towards the end result that is not physically building the model. This includes time getting familiar with the building elements, and manipulating and processing the information delivery format. Rework includes any disassembling or reassembling of a previously built portion of the model. Finally, delay due to rework includes time spent reprocessing the information delivery medium after rework occurs. Notes to the activity being performed during each segment can also be taken on the sheet. A sample five-minute rating sheet from Oglesby et al. (1989) can be seen in Appendix C. To ease in the assessment of the five-minute rating, the subjects were videotaped for the sole purpose of data collection for the five-minute rating. The researcher prepared proper documentation to the University of Kentucky's Office of Research Integrity (ORI), which is the University's in house Institutional Review Board (IRB). The IRB approved the study prior to any tests beginning and closed the study once all data had been collected and analyzed. A complete sample of the actual Five-Minute Rating template used in the study can be seen in Appendix C with the date and personally identifiable information (PII) number redacted for confidentiality.

4.2.4. Spatial Orientation Ability

Spatial orientation testing description and methods were thoroughly introduced in Section 3.2.2. This aspect of an individual's spatial abilities is most relatable to their ability to complete the task in a timely, effective manner. Since the Card Rotations and Cube Comparisons test spatial orientation ability in two dimensions and three dimensions respectively, subjects should have a high correlation between performance on the tests and performance of the task in similar dimensions. That is, individuals with a high score on the Card Rotations test (2D) should also have evaluations on their performance with the two dimensional drawing set. Likewise, those with high Cube Comparison scores (3D) should perform well with the three dimensional information formats.

The Card Rotations has a total of 160 available points, while the Cube Comparisons test only has 42 available points. Each test is graded as the number answered correctly minus the number answered incorrectly, therefore, it is possible to finish with a negative overall score. Values for total score and percent correct will be reported in the analysis section.

4.3. Subjective Outcome Measures

The previous data is used to assist in evaluating performance of individual's with various information formats, however, the cognitive aspects are measured subjectively. In addition, data was collected post-test on preferences and situational use of various information formats. The following sections continue this discussion.

4.3.1.Mental Workload Measurement

As mentioned in Sections 3.3 and 3.3.1, there are several ways to measure mental workload and motivation behind use of the NASA-rTLX as the subjective assessment. The NASA-rTLX queries subjects on their relative rating of difficulty in using each specific information format based on six main categories. The categories are as follows:

- Mental Demand (Easy or demanding, simple or complex, exacting or forgiving);
- Physical Demand (Easy or demanding, slow or brisk, slack or strenuous, restful or laborious);
- Temporal Demand (Slow and leisurely or rapid and frantic);
- Performance (How successful or how satisfied were you with your performance?);
- Effort (How hard did you have to work to accomplish your performance?); and
- Frustration (How discouraged, stressed, irritated, and annoyed versus gratified, relaxed, content, and complacent did you feel during the task?).

The subjects completed a NASA-rTLX form immediately after completing the building task with each information format; 2D drawings, 3D computer monitor, and physical model. Appendix D contains a sample blank form of the NASA-rTLX instrument.

4.3.2. Post-Test Questionnaire

At the conclusion of the demographic questionnaire, spatial orientation testing, and all three building tasks, the subjects are asked to complete a post-test questionnaire. There are several desired qualitative outcomes from the post-test questionnaire. First, the preferred information format for the just completed test is queried and asked for an explanation. Then, the subjects are asked for their preferred information format in various real construction tasks. As literature has shown, information formats are task dependent, and the selected construction scenarios reflect tasks where a two dimension model or three dimension model is superior. There are four presented scenarios that are tasks associated with various trades on a construction project. The four scenarios are as follows:

- You are a structural steel subcontractor and need to plan and present an erection sequence, which information delivery format(s) would you use to complete the task?
- If you are calculating the necessary cubic yard of concrete for an upcoming slab pour, which information delivery format(s) would you use to complete the task?
- If you are a mechanical, electrical, or plumbing engineer and need to design piping runs with sufficient access space, which information delivery format(s) would you use to complete the task?

- If you are estimating the quantity of earthwork that will have to be cut and/or filled on a project, which information delivery format(s) would you use to complete the task?

Finally, another set of 2D drawings are presented to the subjects and asked whether the set is different than the model set that was just completed and what the differences are. After several mentally demanding questions, this question seeks to test the ability of the subjects to retain the information used in the previous assessment. The model is slightly modified from the original drawing set. A copy of the post-test questionnaire and the model comparison drawing set can be seen in Appendix E and F respectively.

4.4. Experiment Procedure

For a visual representation of the study procedure, see Figure 4.11. Each subject begins by completing the informed consent form after reading through its entirety, followed by the demographic questionnaire. Then the subjects complete the spatial rotations baseline examinations beginning with the card rotations test and then the cube comparisons test. After those tests are completed, the subjects are then acquainted with the building elements. When the subjects are comfortable with the building elements, one of the information formats is presented and the timer starts. After the subjects stop the timer at completion, the subjects are given the NASA-rTLX measure. Presenting an information format and completing the building and NASA-rTLX form is repeated until all information formats are exhausted. This means completing the cycle with a set of two dimensional drawings, a three dimensional computer model, and a physical model. After task completion, the subjects are given the post-test questionnaire. When this is completed, the experiment is complete, and data analysis begins. To control and identify a potential learning curve, the sequence that the models were completed was rotated. With three separate models, there were six distinct sequences that rotated sequentially through participating subjects and are as follows:

- Sequence 1 - 2D drawings, then 3D computer model, then physical model;
- Sequence 2 – 3D, Physical, 2D;
- Sequence 3 – Physical, 2D, 3D;
- Sequence 4 – 2D, Physical, 3D;
- Sequence 5 – 3D, 2D, Physical; and
- Sequence 6 – Physical, 3D, 2D

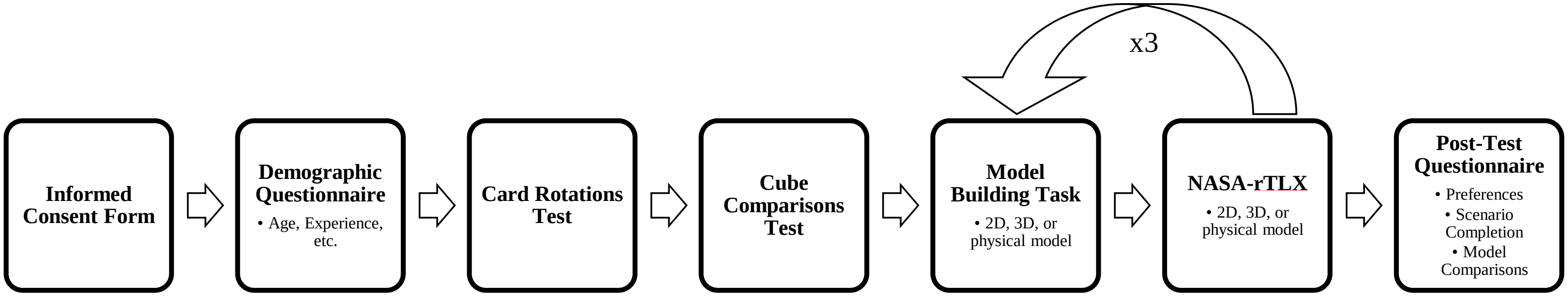

Figure 4.11 Experiment procedure flow chart

4.5. IRB Regulations

The study is inherently an investigation of cognitive and behavioral studies including videotaping of completed tasks. While the examination presents no more than minimal risk to the participating subjects, the PI was required to complete all necessary steps for approval of a human behavioral study with the University. At the University of Kentucky, this organization is the Office of Research Integrity (ORI), which reviews all research protocols by the governing principles of Institutional Review Boards (IRB) across the United States.

This research was filed under a Nonmedical Expedited Review with the IRB, as there is no greater than minimal risks. The process involved the completion of several forms as long as submissions of all relevant documents that will be included in the examination, most notably the consent form. Two different consent forms were required for the study, one designed for the practitioners and one designed for the student participants. This was necessary due to the compensation the practitioners could have in the form of a raffle for a gift card to a home improvement store. The student participation did not carry any special incentive or benefit to participating in the study.

The ORI at the University of Kentucky approved the research protocol on May 10th, 2012 and approval extended until May 9th, 2013. The IRB submission forms A and B, notice from the ORI of the study approval, and the approved consent forms (Form C) can be seen in Appendix G. Specific IRB submissions that potentially compromise the identity of the participating subjects, such as Form N, are not included in the appendix.

The PI filed for study closure in March 2013 prior to the end of approval date of May 9th, 2013.

CHAPTER FIVE: RESULTS AND ANALYSIS

5.1. Analysis Strategy

To meet the primary objective, a defined outcome for an effective presentation format of spatial information must be presented. As mentioned previously, Emmitt and Gorse (2003) defines effective engineering communication formats as quick, simple, and easily interpretable. Based upon the outcome measures taken, there are four main dependent variables to identify effective formats. To identify a quick format, the time to complete the task is used as the dependent variable. To identify a simple format, one that requires the least amount of mental workload, the outcomes from the NASA-rTLX instrument is the dependent variable. Finally, easily interpretable information yields highly effective work and limited errors. The direct work rate (amount of time spent building the desired product) and rework rate (amount of time spent correcting errors) present valid results to describe an easily interpretable format.

5.1.1.Variables

Chapter Four presented the methodology behind the research, and in the process, identified several variables and outcomes of different measures. Subsequently, Table 5.1 outlines all of the source, the names, and a brief description of the variables that were acquired for each subject that completed the assessments.

Table 5.1 Variables Acquired During Experiment

Source	**Variable Name**	**Description**
NASA-rTLX	Composite Workload*	Measure of the total amount of workload required to complete the task.
	Mental Demand	How much mental and perceptual activity was required? Was the task easy or demanding, simple or complex, exacting or forgiving?
	Physical Demand	How much physical activity was required? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
	Temporal Demand	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
	Operator Performance	How successful do you think you were in accomplishing the goals of the task set by the experimenter? How satisfied were you with your performance in accomplishing these goals?
	Effort	How hard did you have to work (mentally and physically) to accomplish your level of performance?
	Frustration	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?
Card Rotations Test	2D Spatial Orientation Performance	Ability to mentally rotate and understand 2D information.
Cube Comparisons Test	3D Spatial Orientation Performance	Ability to mentally rotate and understand 3D information.
Timer	Time to Completion*	Time to complete the task

continued on next page

Source	**Variable Name**	**Description**
Five Minute Rating	Direct Work Percentage*	% of time spent on physically building of the model towards the final product
	Indirect Work Percentage	% of time spent towards the end result of the final product that is not physically building the model (i.e. manipulating the information delivery format, planning action, gaining familiarity with the model pieces)
	Rework Percentage*	% of time spent disassembling or reassembling of a previously built portion of the model
	Delay Due to Rework Percentage	% of time spent reprocessing the information delivery medium after rework occurs
Demographic Questionnaire	Order of Completion	Order of delivery format task completion. Shows transfer of knowledge from one format to another.
	Years of Experience	Years of experience in industry requiring drawing interpretation
	Age	Age of subject
	Gender	Gender of subject
	Occupation	Practitioner or student
	Drawing Reference Frequency	How frequent subject references design or construction drawings in their work (5 point Likert scale)
	Course Hours	Number of coursework hours completed (students only)
	CAD Experience	High/Low experience in computer aided design (CAD)
Post-Test Questionnaire	Preferred Format	Preferred information format for experiment
	Steel Erection Sequence	Preferred information format for planning steel erection sequence
	Concrete Slab Placement	Preferred information format for calculating quantity of concrete necessary for a slab placement
	MEP Run Coordination	Preferred information format for coordinating piping installations being mindful of access space
	Cut/Fill Quantities	Preferred information format for calculating amount of cut and fill for earthwork operations
	Model Comparison	Is this new drawing set the same model as the one completed in the experiment?

* Dependent variables

Using the acquired variables listed above, several quantitative and qualitative analysis techniques can be results to arrive at results and recommendations.

5.1.1. One-Way Analysis of Variance (ANOVA)

A key statistical measure to identify an effective information delivery format is the analysis of variance (ANOVA) procedure. ANOVA models seek to test whether there is a difference between means of several populations (Dielman, 2005; Fellows and Liu, 2008). The often performed procedure estimates statistically significant differences between the means through an F value, while also measuring the amount of variation in the dependent variable that is explained by the independent variables (η^2) (Goodrum and Haas, 2002b; Goodrum and Haas, 2004; Dielman, 2005; Fellows and Liu, 2008; Wang et al., 2008; Goodrum et al., 2009; and Goodrum et al., 2011).

A one-way ANOVA model with K populations can be written as

$$y_{ij} = \mu_i + e_{ij}$$

Where y_{ij} is the jth observation from population i, μ_i is the population mean for population i, and e_{ij} is a random disturbance for the jth observation from population i (Dielman, 2005). The one-way ANOVA model has three main assumptions made about the disturbances to derive statistical outcomes. They are that e_{ij} has a mean of zero, has constant variance, and are normally distributed. The hypothesis tested through the F-test is whether the means of all K populations equal or are they not equal. The testing scenarios can be written as

$$H_0 = \mu_1 = \mu_2 = \cdots = \mu_K$$

$$H_a = Not\ all\ means\ are\ equal$$

As mentioned, the *F* statistic is used to test the null and alternate hypotheses. The test statistic is written as

$$F = \frac{MSTR}{MSE}$$

Where MSTR is the mean square due to treatments (explanatory variables) and MSE is the mean square error. The test statistic has an *F* distribution with *K – 1* numerator and *n – K* denominator degrees of freedom, where *K* is the number of populations and *n* is the total sample size (Dielman, 2005). The other often reported value from an ANOVA analysis is the eta squared, or η^2, which is the ratio of $SS_{BETWEEN}$ (between sum of squares) to SS_{TOTAL} (total sum of squares). η^2 measures the proportion of the variance in the dependent variable explained by the independent variable.

The decision rule for the ANOVA procedure then becomes

$$Reject\ H_0 if\ F > F(\alpha; K-1, n-K)$$

$$Do\ not\ reject\ H_0 if\ F \leq F(\alpha; K-1, n-K)$$

For this study, the three populations tested are individuals completing the experiment using the two dimensional drawing set, individuals completing the experiment using the three dimensional computer model, and individuals completing the experiment using the three dimensional printed, physical model. By conducting an ANOVA analysis with each population against the dependent variables, a statistical argument can be made towards which information format yields better performance. IBM SPSS Statistics 20 statistical software was utilized for all the following analyses.

5.1.2. Simple and Multiple Regression Analysis

The ANOVA analysis provides insight on differences in means among the included variables. While that statistical procedure helps compare means, it does not describe relationships among variables. A regression analysis provides a more detailed investigation to understanding the interaction that certain variables may have with each other. For example, it would be useful to know if the amount of mental workload required to use the computer has a statistically significant influence on the time it takes to complete the task and, if so, how much of an influence. These observations are made possible through a regression analysis, whereas, the ANOVA analysis stops at comparing differences in means.

Regression analysis is used to describe, explain, or predict relationships among variables. The simple regression equation is typically given in the form

$$y = b_0 + b_1 x$$

where y is the dependent variable relating to x, or the independent or explanatory variable, b_0 represents the y intercept of the linear relationship, and b_1 is the slope of said line (Dielman, 2005).

Similar to the ANOVA analysis, there are several assumptions that must be made about the sample to infer findings upon the population. The assumptions are stated as:

- The expected value of the disturbances is zero: E(e_i) = 0. Essentially, the regression line passes through the condition means of the independent variable. Or, the population regression equation is linear in the explanatory variable.
- The variance of each e_i is equal to σ_e^2. This assumption means that each of the distributions along the regression line has the same variance regardless of the value of x.
- The e_i are normally distributed.

- The e_i are independent. This is an assumption that is most important when data are gathered over time. When the data are cross-sectional, as is for this study, this assumption is not a concern (Dielman, 2005).

The above discussion on regression analysis has focused on the case where there is only one explanatory or independent variable. However, often studies require a more, robust model that includes multiple explanatory variables to describe the relationship with the dependent variable. In these scenarios, a multiple linear regression equation for K number of explanatory variables is used in the form

$$\hat{y} = b_0 + b_1x_1 + b_2x_2 + \cdots + b_Kx_K$$

where b_0, b_1, b_2, …, b_k are the least-squares regression coefficients for explanatory variables x_1, x_2, …, x_K. The assumptions about the population regression line for multiple linear regressions are the same as the assumptions presented for simple linear regressions (Dielman, 2005).

5.2. Model Comparison Results

5.2.1. One-Way ANOVA Analysis for 2D Drawings, 3D Interface, and Physical Model by Dependent Variables, All Subjects

The results from a one-way ANOVA analysis for all subjects for each information format by time to completion, composite workload, direct work rate, and rework rate are presented in Table 5.2. For the model with all subjects, there were 30 participating subject, resulting in 89 complete building experiments. One individual could not stay to complete a third model, which prevented the sample size from reaching 90. The full SPSS output can be found in Appendix H.

Table 5.2. ANOVA results: Model type by dependent variables, all subjects

	Model Type by Dependent Variables					
Dependent Variables	**Mean**	**N**	**df**	**F**	**p**	**η^2**
Time to Completion	10.69	89	86	1.25	0.29	0.028
Composite Workload	32.92	89	86	0.52	0.60	0.012
Direct Work Rate	76.92	89	86	19.80*	0.00	0.315
Rework Rate	4.12	89	86	0.73	0.49	0.017

*significant above 95%

The ANOVA results for all subjects show that only direct work rate is statistically significant between the information format groups. Although it was the only significant different average, there is value in looking at the means for each information format based upon the presented dependent variables. Table 5.3 shows the mean for each model type as well as the overall mean for the group for all subjects. For a graphical version and percent differences, see Figures 5.1, 5.2, 5.3, and 5.4 for the time to completion, composite workload, direct work rate, and rework rate respectively.

Table 5.3 Comparison of means of information format by dependent variables, all subjects

Model Type	Time to Completion (minutes)		Composite Workload (0-100)		Direct Work Rate (%)		Rework Rate (%)	
	Mean	**Overall Mean**	**Mean**	**Overall Mean**	**Mean**	**Overall Mean**	**Mean**	**Overall Mean**
2D Drawings (n = 30)	10.44	10.69	33.81	32.92	75.13	76.92	3.23	4.12
3D Interface (n = 30)	11.55		34.88		66.85		5.62	
Physical Model (n = 29)	10.09		30.15		88.45		3.57	

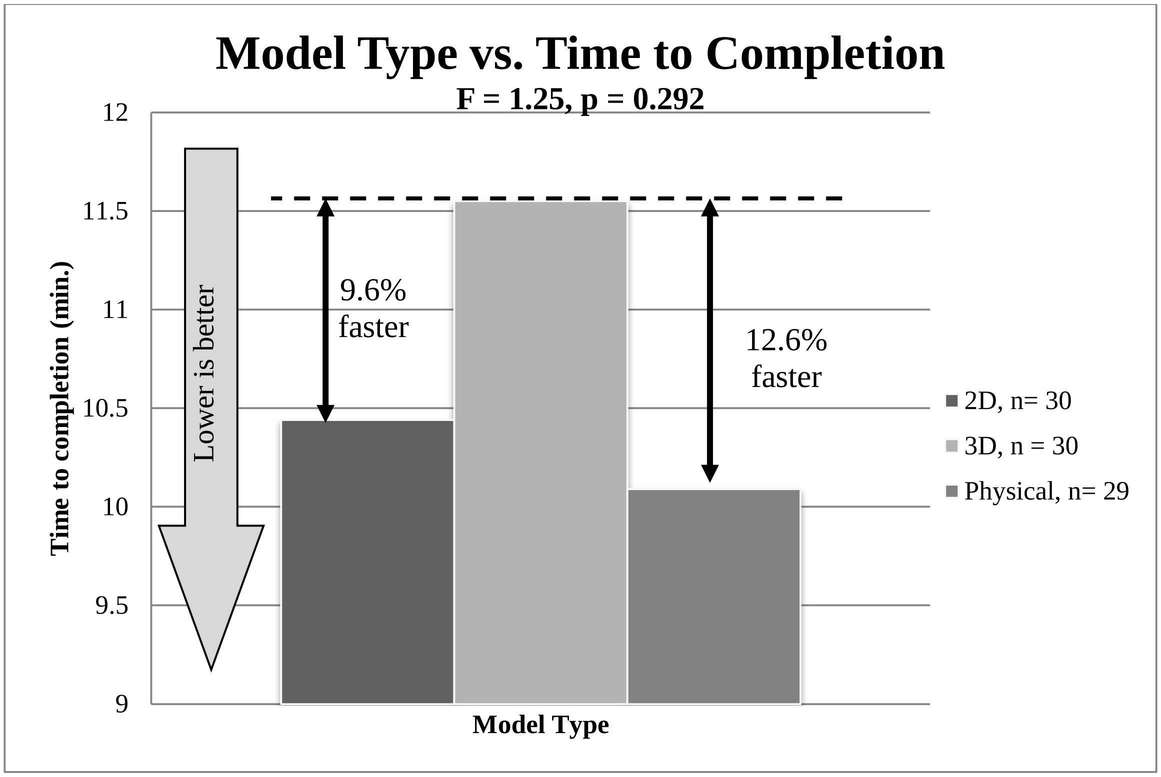

Figure 5.1 Model type versus time to completion, all subjects

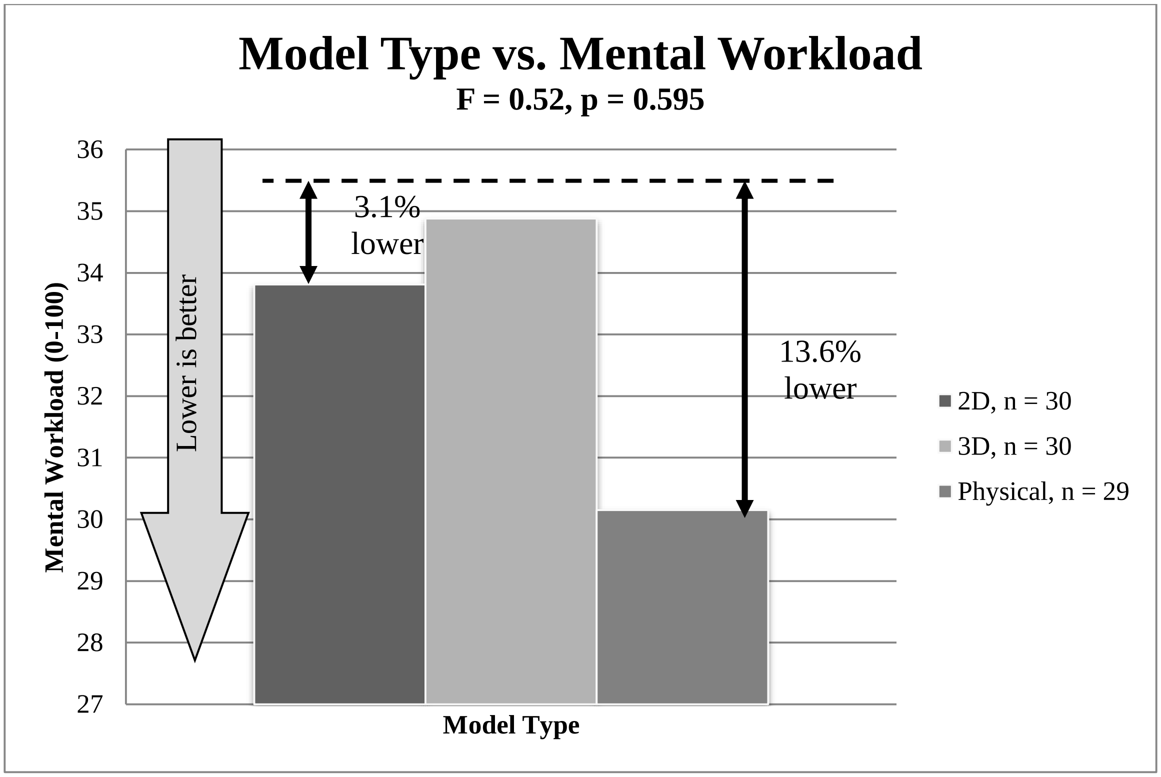

Figure 5.2 Model type versus composite mental workload, all subjects

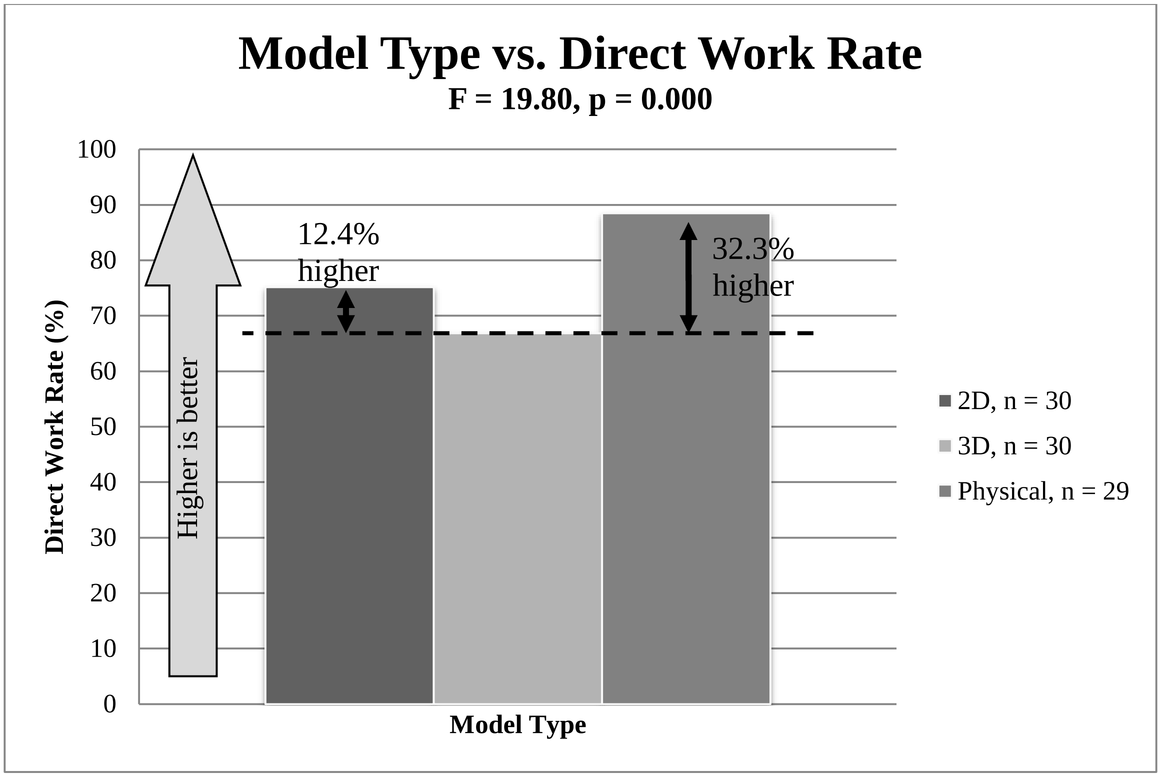

Figure 5.3 Model type versus direct work rate, all subjects

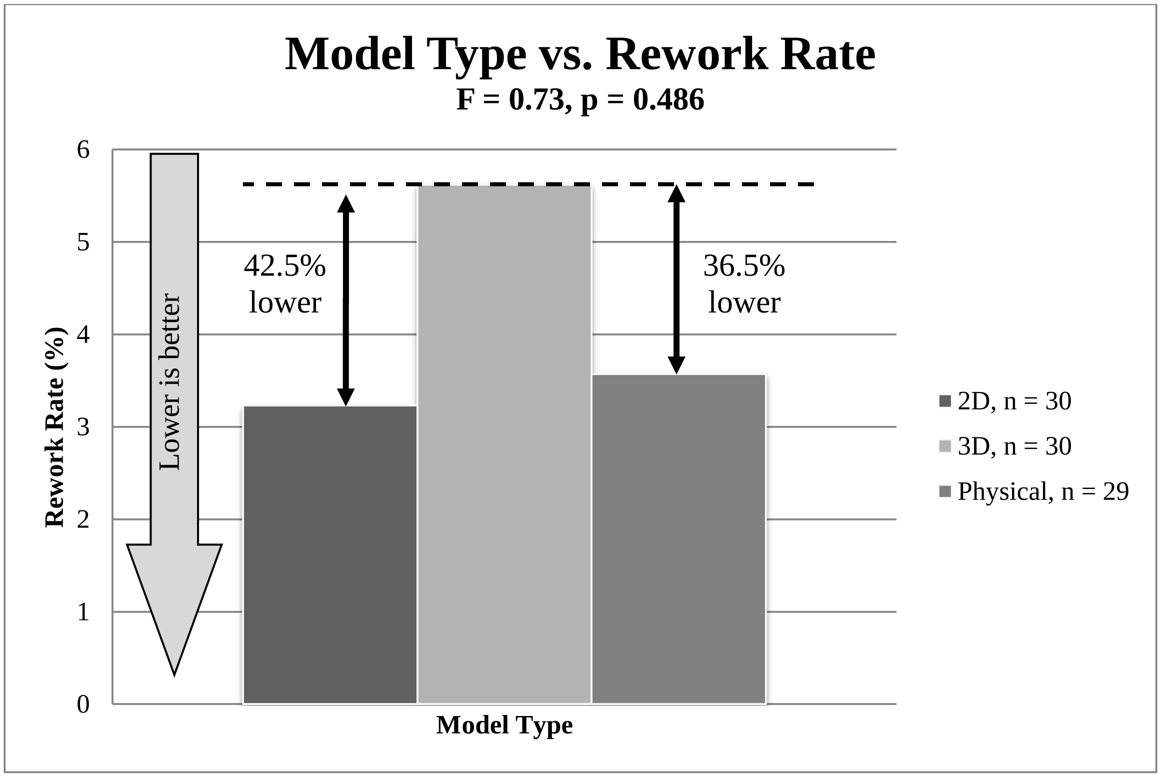

Figure 5.4 Model type versus rework rate, all subjects

From the above Table 5.3, the results indicate that, based on the defined dependent variables, the physical model performs the best, while the 3D interface lags behind all. In the statistically significant different category of direct work rate, the physical model has a direct work rate that is 18% and 32% higher than the 2D drawings and 3D computer model respectively.

5.2.2. Post-Hoc Analysis for All Subjects

Although the previous ANOVA discussion focuses on the key dependent variables, there are several other variables acquired during the study. Some of these variables results in statistically significant differences in means between the different model types. To quantify these statistically significant differences, there are several post hoc tests available to compare multiple means. The original post hoc test was Fisher's Least Significant Difference (LSD) test. This test compared multiple means through a series of *t*-tests.

However, no adjustment is made to the error rate for the comparisons. In the assumptions of a *t*-test, the sampling distribution is intended for only one test. When multiple comparisons are made, the true alpha value for significance is lower than 0.05, which is the value assumed in the LSD test (Dielman, 2005).

Another, more reasonable post hoc test is the Bonferroni method. Bonferroni uses *t* tests to perform pairwise comparisons but sets the critical alpha value as the experimentwise error rate divided by the total number of tests. This corrects for the effect that multiple tests has on the tested *t* value (Dielman, 2005).

The Bonferroni method is utilized in this study for the post hoc analysis of the variables that were shown to have significant differences in their means between the model types. In the full subject model, the variables with significant differences between their means are the direct work rate, indirect work rate, and delay due to rework rate. The results from the Bonferroni approach are reported in Table 5.4.

Looking at the results, the direct work rate has a significant difference between the 2D drawing set and the physical model, as well as between the 3D computer model and the physical model. The direct work rate for the physical model is 13% and 20% higher for the physical model than the 2D drawings and 3D computer model respectively. The indirect work rate for the physical model is 13.5% and 17.6% lower than the 2D drawings and 3D computer model respectively.

Finally, the delay due to rework rate has differences between the 2D drawings and 3D computer model, and between the physical model and 3D computer model. The delay due to rework rate for the 2D drawings is 1% lower than the 3D computer model. In addition, the physical model's delay due to rework rate is 1% lower than the 3D computer model.

When it comes to these post hoc variables, the physical model provides improved results over both the 2D drawings and 3D computer model in direct work, indirect work, and delay caused by errors. The Bonferroni shows a significantly strong (p-values < 0.00) improved performance in the productivity metrics for the physical model. While the results are applied for this simple building task, it is certainly possible that these numbers may translate to construction tasks where spatial relations are a concern.

Table 5.4 Bonferroni post-hoc analysis for all subjects

Multiple Comparisons

Bonferroni

Dependent Variable	(I) Model	(J) Model	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
DW	0	1	7.34	3.26	.080	-.6160	15.2940
		2	-13.10*	3.29	.000	-21.1214	-5.0748
	1	0	-7.34	3.26	.080	-15.2940	.6160
		2	-20.44*	3.29	.000	-28.4604	-12.4138
	2	0	13.10*	3.29	.000	5.0748	21.1214
		1	20.44*	3.29	.000	12.4138	28.4604
IW	0	1	-4.16	2.20	.185	-9.5187	1.2020
		2	13.47*	2.21	.000	8.0603	18.8729
	1	0	4.16	2.20	.185	-1.2020	9.5187
		2	17.62*	2.21	.000	12.2186	23.0312
	2	0	-13.47*	2.21	.000	-18.8729	-8.0603
		1	-17.62*	2.21	.000	-23.0312	-12.2186
DRW	0	1	-.91*	.357	.039	-1.7782	-.0338
		2	.10	.360	1.000	-.7747	.9846
	1	0	.91*	.357	.039	.0338	1.7782
		2	1.01*	.360	.019	.1313	1.8906
	2	0	-.105	.360	1.000	-.9846	.7747
		1	-1.01*	.360	.019	-1.8906	-.1313

*. The mean difference is significant at the 0.05 level.

DW = Direct Work Rate

IW = Indirect Work Rate

DRW = Delay Due to Rework Rate

5.2.3. ANOVA Comparison of 3D Displays for All Subjects

The natural alternative to two dimensional displays, such as a conventional set of construction drawings, would be investigating three dimensional displays. In this research, two different 3D displays were tested in the form of a 3D computer model and a 3D physical model. By comparing subject’s performance with the 3D displays, insights into a better alternative can be found. Results from the ANOVA and a comparison of means for each output are seen in Tables 5.5 and 5.6 followed by graphical representations of Table 5.6 in Figures 5.5, 5.6, 5.7, and 5.8.

Table 5.5. ANOVA results: physical or 3D model type by dependent variables, all subjects

	Model Type by Dependent Variables					
Dependent Variables	**Mean**	**N**	**df**	**F**	**p**	**η^2**
Time to Completion	10.81	59	57	1.856	0.178	0.032
Composite Workload	32.48	59	57	0.804	0.374	0.014
Direct Work Rate	77.83	59	57	30.789*	0.000	0.351
Rework Rate	4.58	59	57	0.638	0.428	0.011

*significant above 95%

Table 5.6 Comparison of Means of Information Format by Dependent Variables, 3D vs. Physical, all subjects

Model Type	**Time to Completion (minutes)**		**Composite Workload (0-100)**		**Direct Work Rate (%)**		**Rework Rate (%)**	
	Mean	**Overall Mean**	**Mean**	**Overall Mean**	**Mean**	**Overall Mean**	**Mean**	**Overall Mean**
3D Interface (n = 30)	11.50	10.81	34.42	32.48	67.79	77.83	5.43	4.58
Physical Model (n = 29)	10.10		30.47		88.22		3.69	

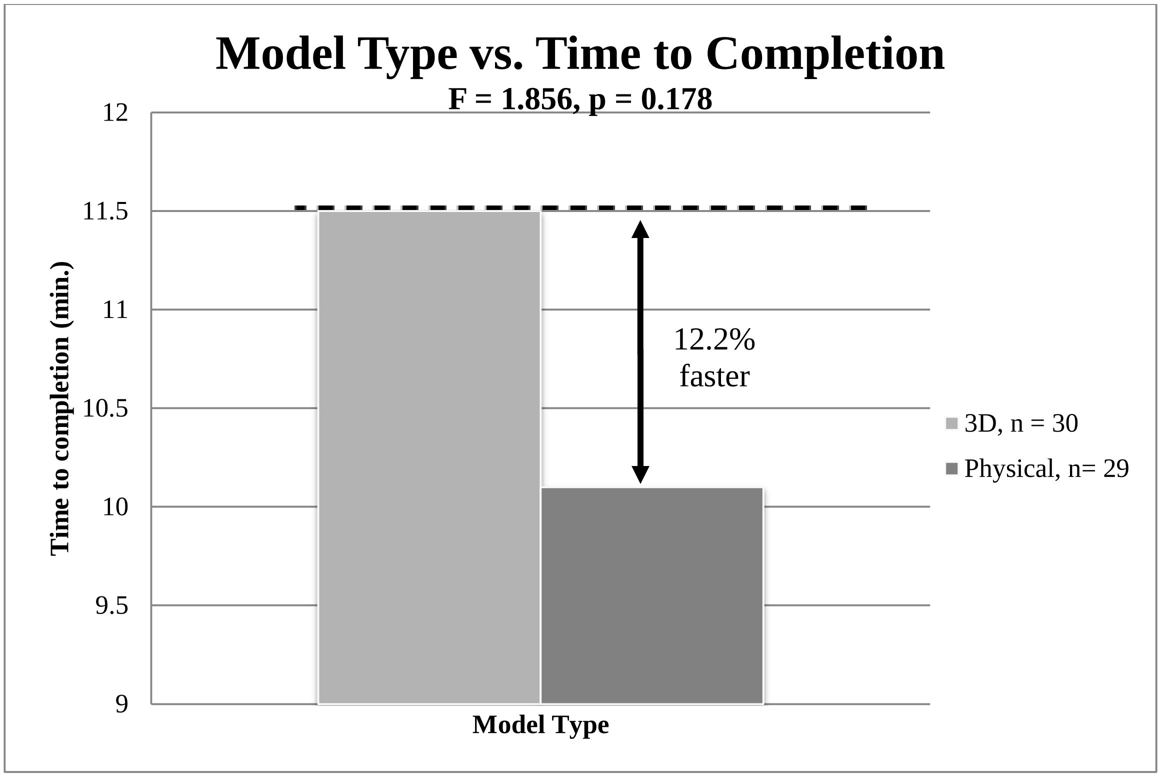

Figure 5.5 3D vs physical model type by time to completion, all subjects

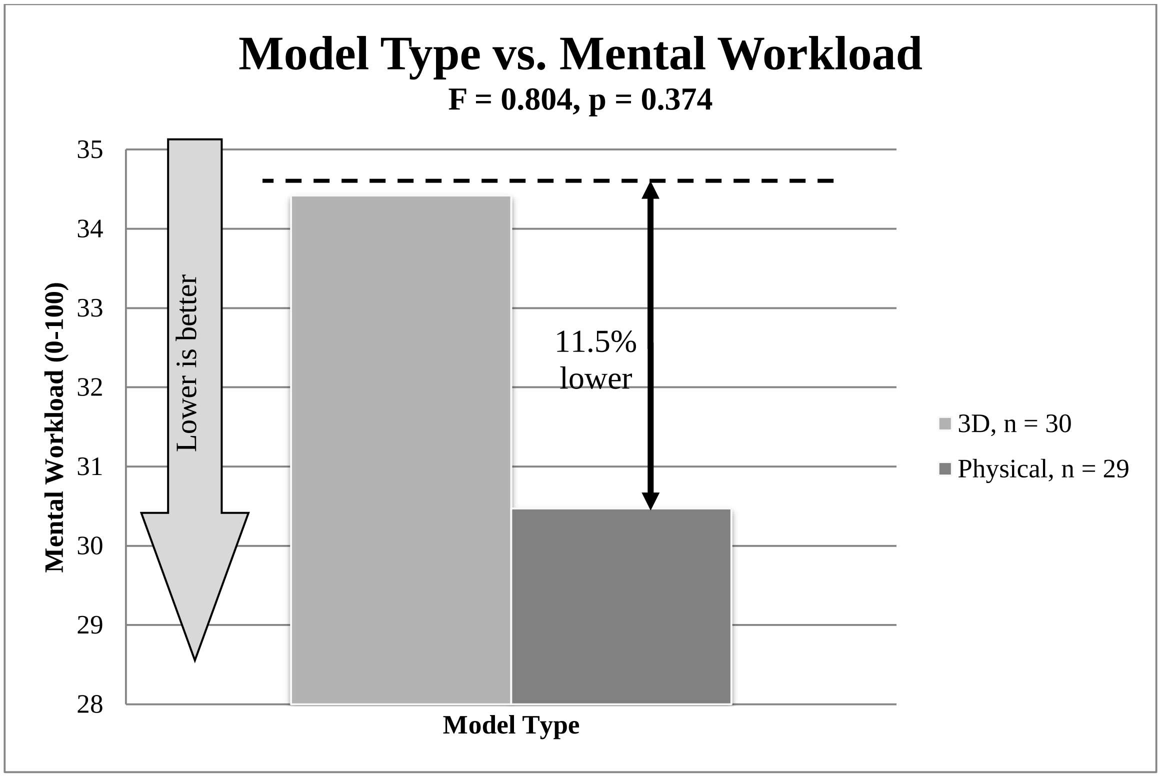

Figure 5.6 3D vs physical model type by composite mental workload, all subjects

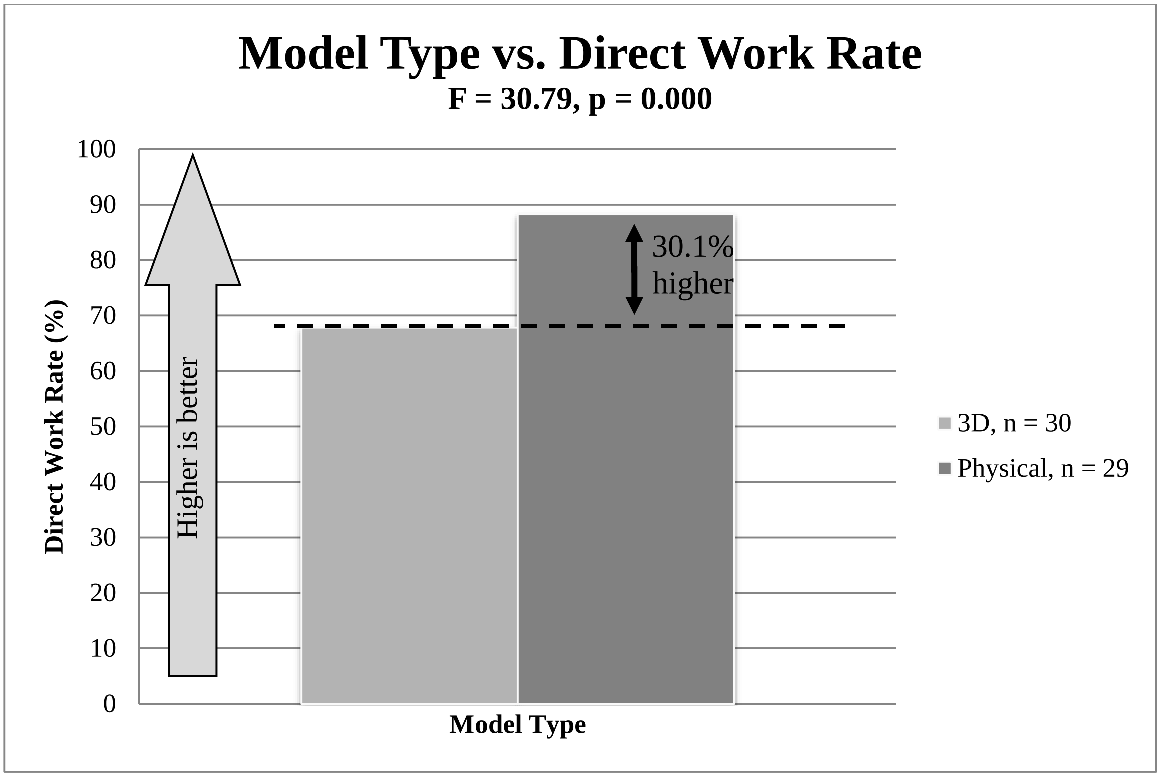

Figure 5.7 3D vs physical model type by direct work rate, all subjects

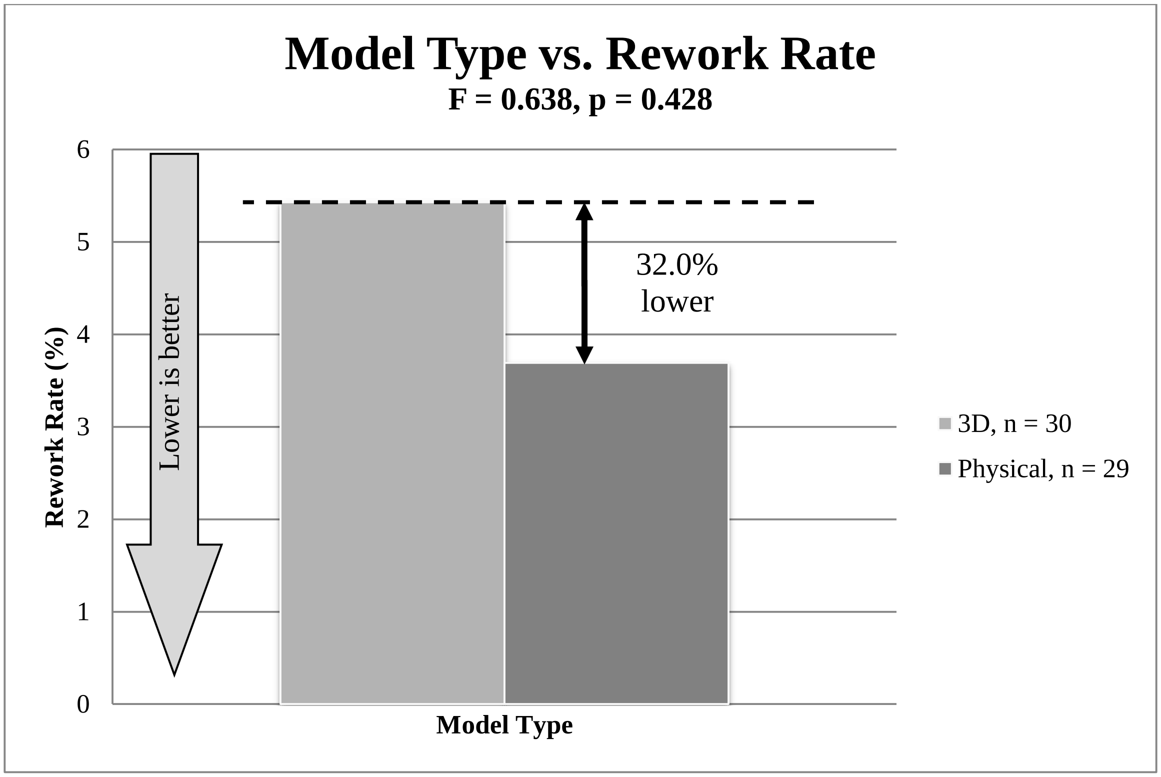

Figure 5.8 3D vs physical model type by rework rate, all subjects

Based on these findings, the physical model tends to perform better than a 3D computer in time to complete an exercise, mental workload, and rework rates. However, the only statistically significant advantage of a physical model over a 3D computer model is in the direct work rate, where the physical model's direct work rate was 30.1% higher.

Including the rest of the variables acquired, there are other statistically significant differences between a physical model and a 3D computer model. Table 5.7 shows the results of an ANOVA analysis for all dependent variables by model type (physical or 3D). A Bonferroni (post-hoc) analysis could not be done as the tested factor, model type, only has two outcomes. The direct work rate, indirect work rate, and delay due to rework rates for the physical model were all statistically significantly different than the 3D computer model. Further, the physical model had more desirable means than the 3D model for all variables. The direct work rate was higher, indirect work rate was lower, and delay due to rework rate was lower for the physical model. The outcomes of this experiment show that a physical model outperforms a 3D computer model as a three dimensional alternative to the traditional 2D drawings.

Table 5.7. Significant ANOVA results: Physical or 3D model type by all variables, all subjects

	Model Type by Dependent Variables					
Dependent Variables	**Mean**	**N**	**df**	**F**	**p**	**η^2**
Direct Work Rate	77.83	59	57	30.789*	0.000	0.351
Indirect Work Rate	16.98	59	57	58.850*	0.000	0.508
Delay Due to Rework Rate	0.58	59	57	30.789*	0.016	0.097

*significant above 95%

5.2.4. One-Way ANOVA Analysis First Model for All Subjects

As outline in the methodology, the subjects complete the model building exercise for three different information formats, but for the exact same structure. Some of the subjects became aware of the repetitive design based on verbal responses and the written response to the model comparison question in the post-test questionnaire. Subsequently, investigating the performance of subjects with the first model presented illustrates the instinctual response to the display format.

Performing the same ANOVA analysis, Table 5.8 shows the results for the model type by the dependent variables for the 30 subjects that completed the experiment. Table 5.9 breaks down the means of each model type for the dependent variables. Similar to previously, the average direct work rate between the first model types is statistically significantly different. The averages for the dependent variables on the first model type are less desirable than the averages for the dependent variables when all trials of the experiment are considered. The average time to completion, composite workload, and rework rates are all higher for the first model, while the average direct work rate is lower. Figures 5.9, 5.10, 5.11, and 5.12 show the averages of the dependent variables by first model type visually.

Table 5.8. ANOVA results: Model type by dependent variables, first model, all subjects

	Model Type by Dependent Variables					
Dependent Variables	**Mean**	**N**	**df**	**F**	**p**	**η^2**
Time to Completion	13.36	30	27	0.922	0.410	0.064
Composite Workload	38.72	30	27	0.156	0.856	0.011
Direct Work Rate	68.60	30	27	13.94*	0.000	0.508
Rework Rate	6.75	30	27	2.266	0.123	0.144

*significant above 95%

Table 5.9 Comparison of means of information format by dependent variables, first model, all subjects

Model Type	Time to Completion (minutes)		Composite Workload (0-100)		Direct Work Rate (%)		Rework Rate (%)	
	Mean	**Overall Mean**	**Mean**	**Overall Mean**	**Mean**	**Overall Mean**	**Mean**	**Overall Mean**
2D Drawings (n = 10)	12.42	13.36	37.67	38.72	72.28	68.60	2.08	6.75
3D Interface (n = 10)	14.94		41.00		52.24		10.35	
Physical Model (n = 10)	12.72		37.50		81.27		7.83	

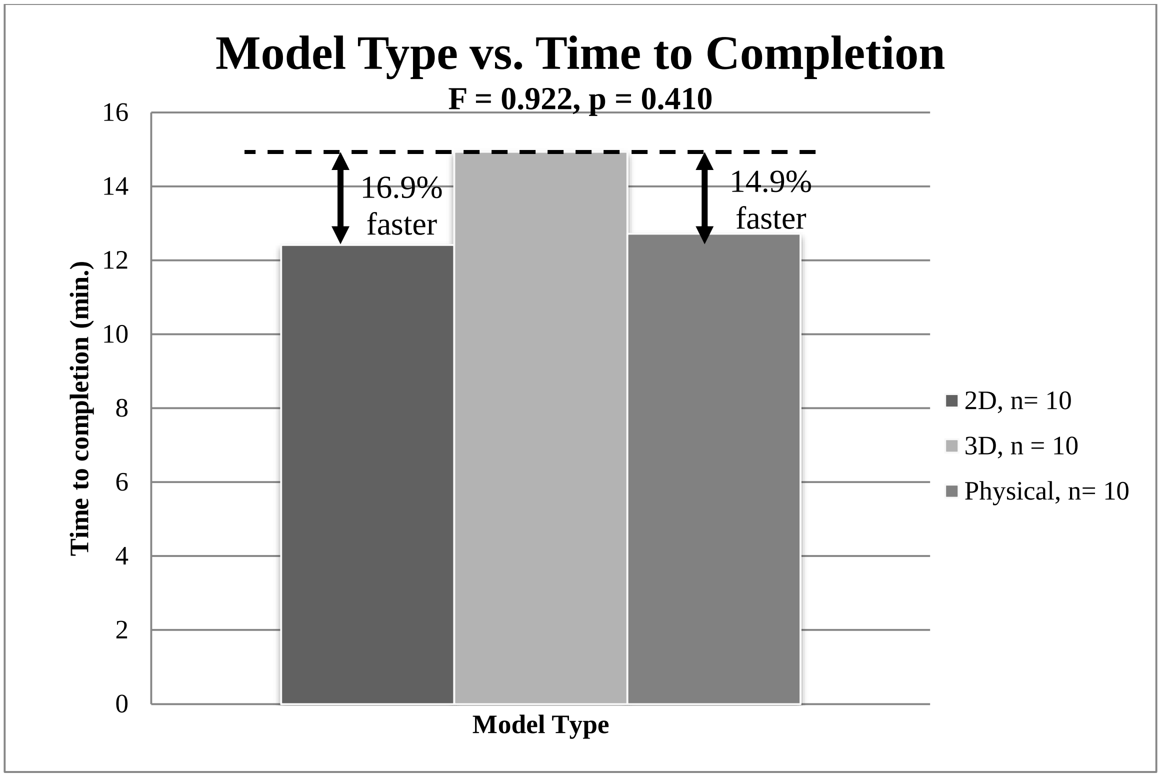

Figure 5.9 First model type versus time to completion, all subjects

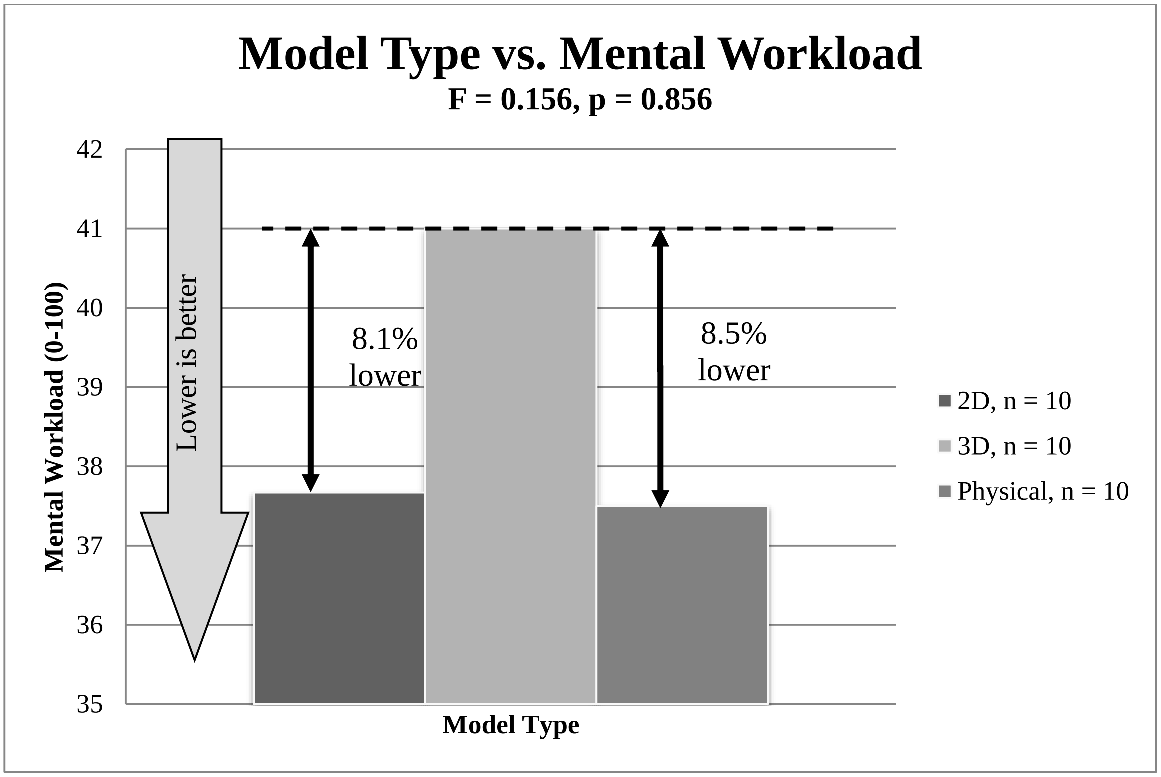

Figure 5.10 First model type versus composite mental workload, all subjects

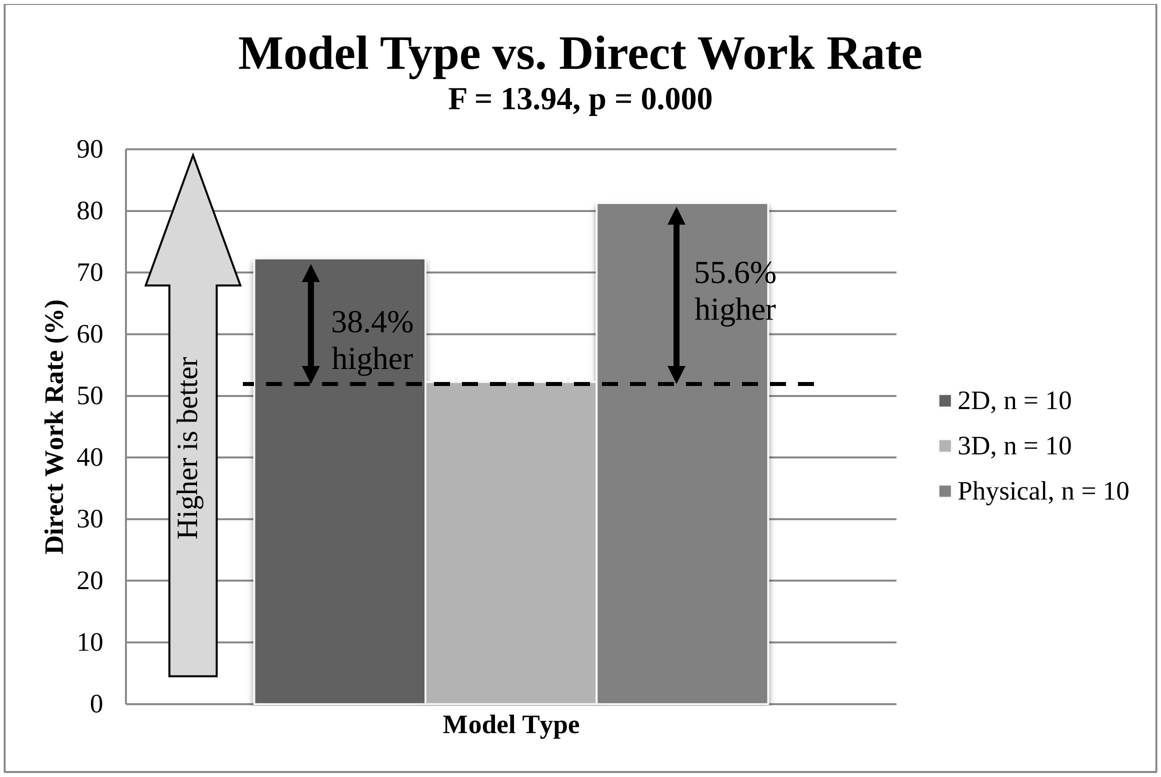

Figure 5.11 First model type versus direct work rate, all subjects

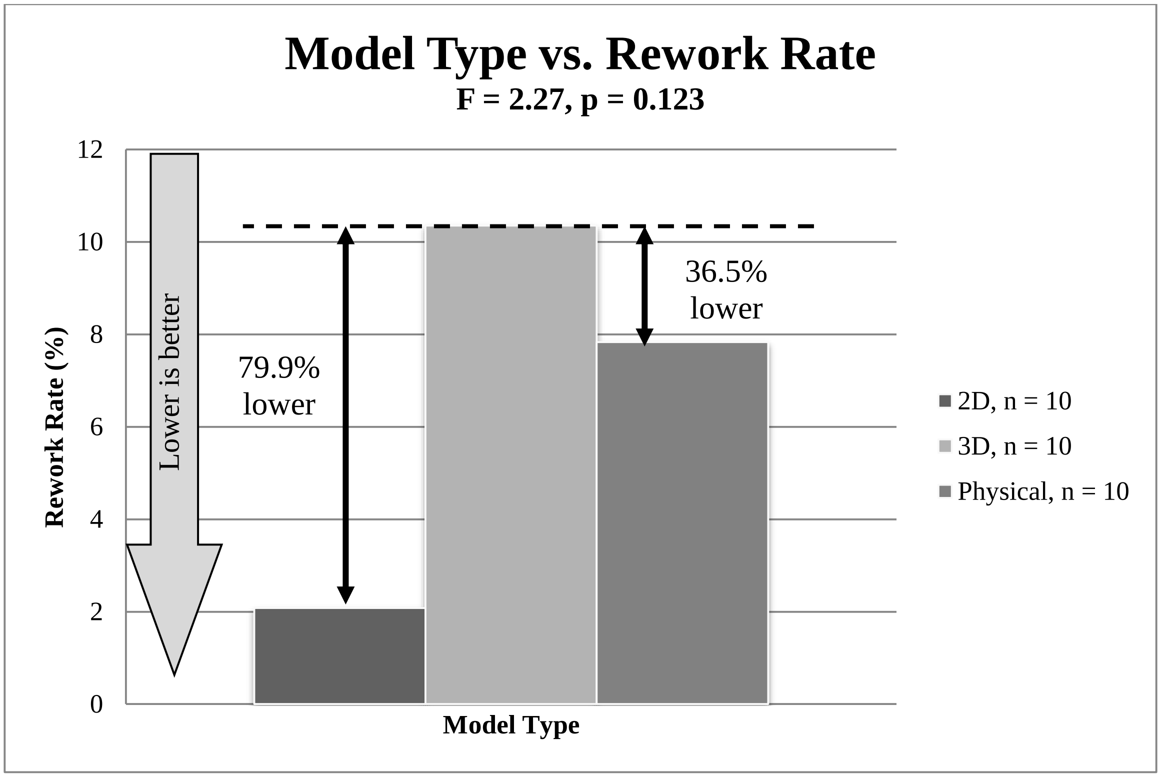

Figure 5.12 First model type versus rework rate, all subjects

5.2.5. Post-Hoc Analysis for First Model Experiments, All Subjects

A Bonferroni analysis for the dependent variables for the first model trials provides a more in-depth look at the statistical differences in the model types. The outcomes are reported in Table 5.10.

The results are similar for the full experiment, but with more drastic differences. The direct work rate is significantly different between the physical model and the 3D computer interface as well as between the 2D drawings and the 3D computer interface. The direct work rate for a physical model is, on average, 29.0% higher than the direct work rate for the 3D computer model. The direct work rate for 2D drawings is 20.0% higher than the direct work rate for the 3D computer model. This, again, reinforces that the 3D computer model does not keep the subjects on task as often as the 2D drawings or physical model.

The indirect work rate for the first model only was also significant between the physical and 3D computer model, as well as between the physical model and 2D drawings. The Bonferroni analysis showed that physical models have 14.92% and 23.67% lower indirect work rates than 2D drawings and 3D computer model respectively. By spending less time doing activities such as interpreting information, the physical model requires less time to get the subjects prepared to do value adding work. This can be a crucial advantage for practitioners that have a natural time and effort pressure from their work.

Finally, the delay due to rework rates are significantly different between the physical model and the 3D computer model and between the 2D drawings and 3D computer model. The physical model yields 2.65% lower delay due to rework rates than the computer model, while the 2D drawings result in 2.83% lower delay due to rework rates than the computer model.

Table 5.10 Bonferroni post-hoc analysis for first model experiments, all subjects

Multiple Comparisons

Bonferroni

Dependent Variable	(I) Model	(J) Model	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
DW	0	1	20.04*	5.63	.004	5.67	34.41
		2	-8.99	5.63	.366	-23.36	5.38
	1	0	-20.04*	5.63	.004	-34.41	-5.67
		2	-29.03*	5.63	.000	-43.40	-14.66
	2	0	8.99	5.63	.366	-5.38	23.36
		1	29.03*	5.63	.000	14.66	43.40
IW	0	1	-8.75	3.44	.051	-17.54	0.04
		2	14.92*	3.44	.001	6.12	23.71
	1	0	8.75	3.44	.051	-0.04	17.54
		2	23.67*	3.44	.000	14.88	32.46
	2	0	-14.92*	3.44	.001	-23.71	-6.12
		1	-23.67*	3.44	.000	-32.46	-14.88
DRW	0	1	-2.83*	0.77	.003	-4.79	-0.87
		2	-0.18	0.77	1.000	-2.14	1.78
	1	0	2.83*	0.77	.003	0.87	4.79
		2	2.65*	0.77	.005	0.69	4.61
	2	0	0.18	0.77	1.000	-1.78	2.14
		1	-2.65*	0.77	.005	-4.61	-0.69

*. The mean difference is significant at the 0.05 level.

DW = Direct Work Rate

IW = Indirect Work Rate

DRW = Delay Due to Rework Rate

5.2.6. One-Way ANOVA Analysis for 2D Drawings, 3D Interface, and Physical Model by Dependent Variables, Practitioners Only

The previous section presented results from an ANOVA analysis for all participating subjects. While the results are meaningful, a better representation of the participating samples would be to run the same analysis with each sample group (students and practitioners). Table 5.11 illustrates the ANOVA results for practitioners for each information format by the dependent variables. The sample size of practitioners for this section is 26 current or recent construction professionals with one experiment left incomplete, resulting in 77 data points. The full SPSS output can be found in Appendix I.

Table 5.11 ANOVA results: Model type by dependent variables, practitioners only

	Model Type by Dependent Variables					
Dependent Variables	**Mean**	**N**	**df**	**F**	**p**	**η^2**
Time to Completion	10.70	77	74	1.73	0.185	0.045
Composite Workload	34.26	77	74	0.47	0.629	0.012
Direct Work Rate	76.53	77	74	16.77*	0.000	0.312
Rework Rate	4.38	77	74	0.68	0.508	0.018

*significant above 95%

The results, again, show that direct work rate is the only variable with a statistically significant difference in the model type. To look more in depth at the difference in means, Table 5.12 highlights the mean for each model type by the dependent variables for practitioners only. Figures 5.13, 5.14, 5.15, and 5.16 graphically presents the same information.

Table 5.12 Comparison of means of information format by dependent variables, practitioners only

Model Type	Time to Completion (minutes)		Composite Workload (0-100)		Direct Work Rate (%)		Rework Rate (%)	
	Mean	**Overall Mean**	**Mean**	**Overall Mean**	**Mean**	**Overall Mean**	**Mean**	**Overall Mean**
2D Drawings (n = 26)	10.02	10.70	33.72	34.26	75.55	76.53	3.41	4.38
3D Interface (n = 26)	11.82		37.27		65.55		6.06	
Physical Model (n = 25)	10.31		31.90		88.06		3.75	

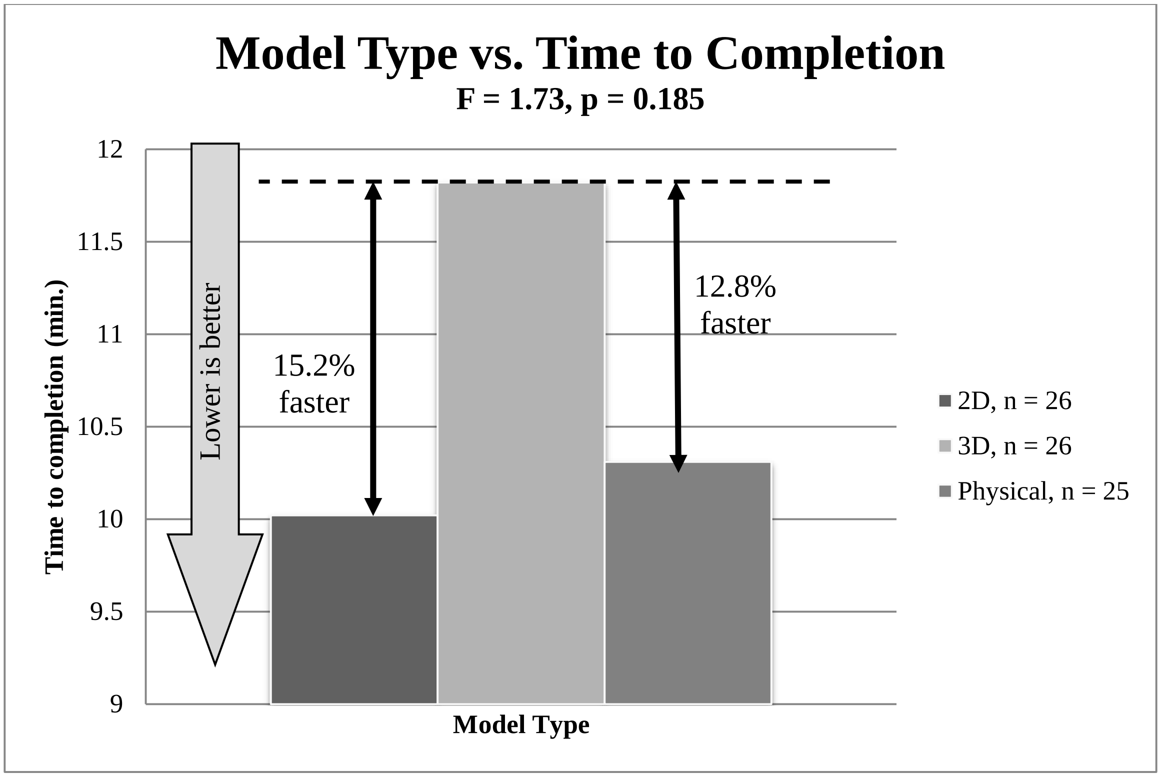

Figure 5.13 Model type versus time to completion, practitioners only

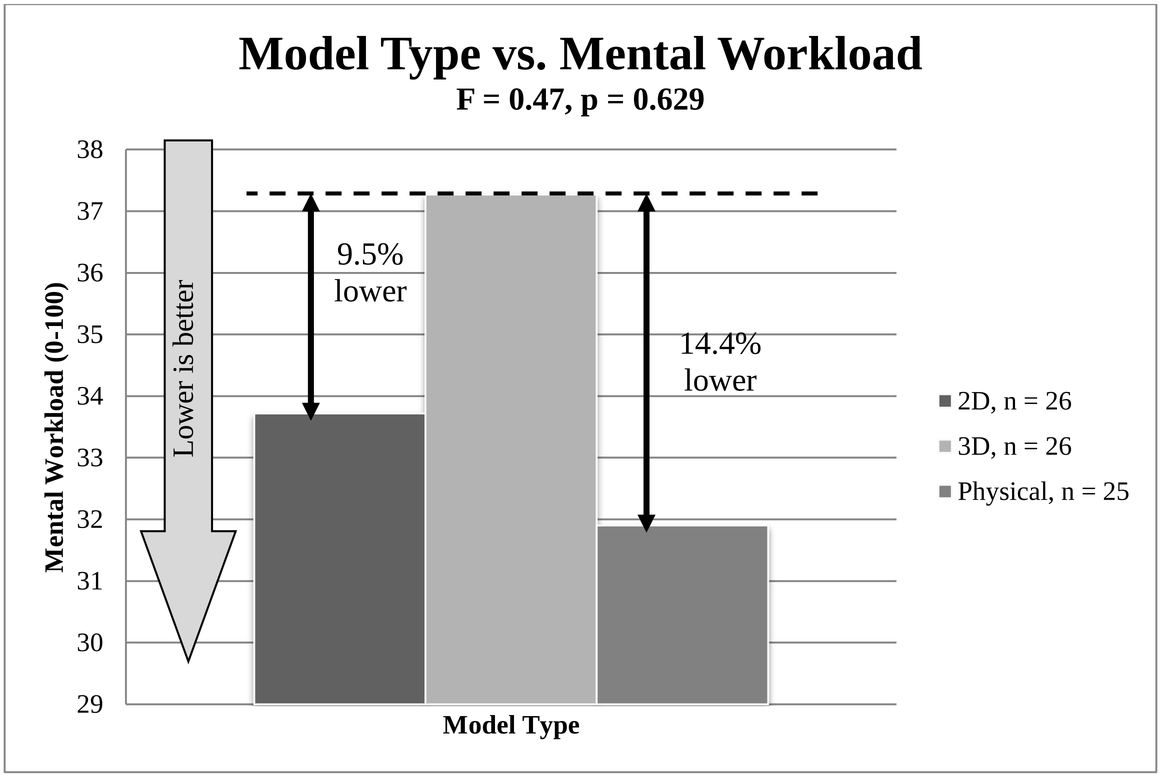

Figure 5.14 Model type versus composite mental workload, practitioners only

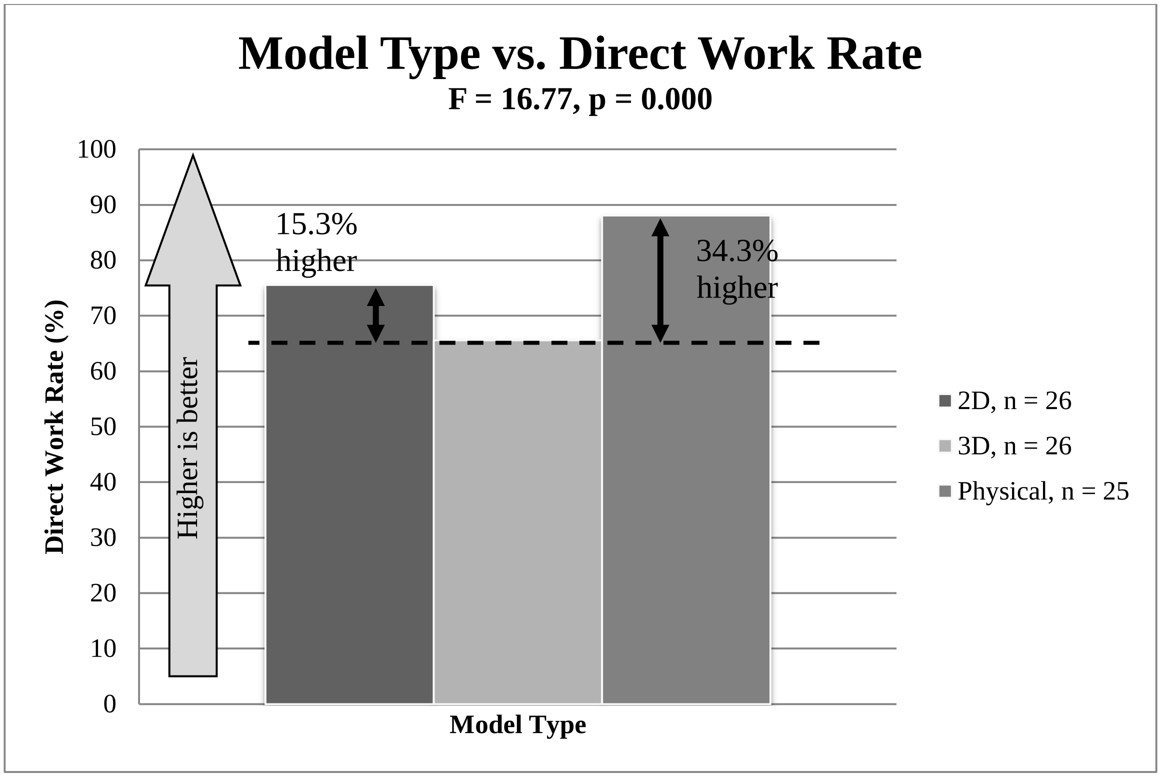

Figure 5.15 Model type versus direct work rate, practitioners only

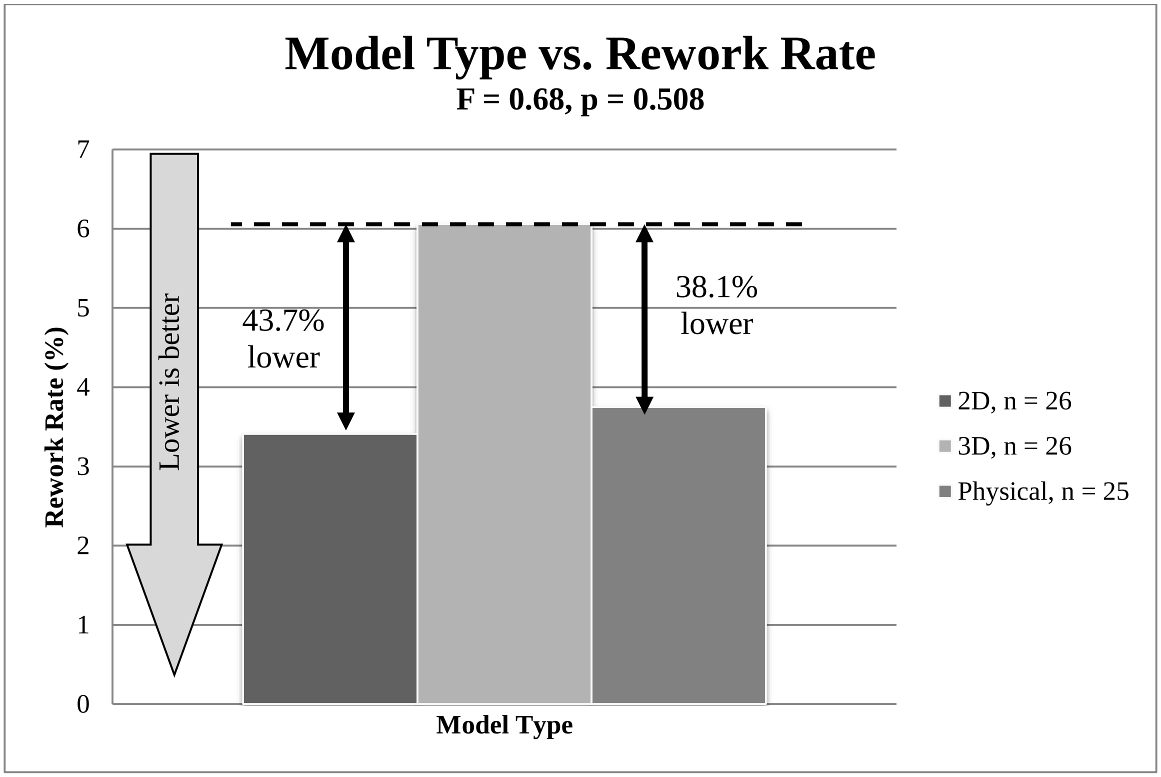

Figure 5.16 Model type versus rework rate, practitioners only

The physical model outperforms the other two formats in all dependent variables except for time to completion in the two dimensional drawing set. This is a reasonable outcome, as practitioners work daily with construction drawings in that format and should be more familiar with interpreting information in that method. In fact, 85% of practitioners responded that they use two dimensional drawings in their day to day activities either “very often” or “daily”.

The direct work rate for the physical model is the statistically significant difference between all of the dependent variables. The physical model allows for 17% and 34% more efficient use of time than the 2D construction drawings and 3D computer model respectively.

5.2.7. Post-Hoc Analysis for Practitioners

Similar to the full model, a post hoc analysis provides more detailed results in the pairwise comparisons by information type. The Bonferroni method is again applied and presented in Table 5.13.

There is a statistical difference between all pairwise comparisons of model type with respect to the direct work rate. The 2D drawings used to complete the experiment have 9.9% higher direct work rates than the 3D computer model. Further, the physical model has direct work rates 12.2% higher than the 2D drawings and 21.1% higher than the 3D computer model.

In regards to the indirect work rate, there are only statistical differences between the physical model and the 2D drawings, and between the physical model and 3D computer model. Using a physical model results in 12.6% lower indirect work rates than 2D drawings and 18.1% lower indirect work rates than 3D computer models.

Finally, the delay due to rework rate only has a significant difference between the physical model and the 3D computer model. The physical model has a delay due to rework rate 1.0% lower than the 3D computer model.

Table 5.13 Bonferroni post-hoc analysis, practitioners only

Multiple Comparisons

Bonferroni

Dependent Variable	(I) Model	(J) Model	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
DW	0	1	8.86731*	3.61850	.050	.0034	17.7313
		2	-12.22811*	3.65451	.004	-21.1803	-3.2760
	1	0	-8.86731*	3.61850	.050	-17.7313	-.0034
		2	-21.09542*	3.65451	.000	-30.0476	-12.1433
	2	0	12.22811*	3.65451	.004	3.2760	21.1803
		1	21.09542*	3.65451	.000	12.1433	30.0476
IW	0	1	-5.47962	2.32921	.064	-11.1853	.2261
		2	12.60480*	2.35238	.000	6.8424	18.3672
	1	0	5.47962	2.32921	.064	-.2261	11.1853
		2	18.08442*	2.35238	.000	12.3220	23.8469
	2	0	-12.60480*	2.35238	.000	-18.3672	-6.8424
		1	-18.08442*	2.35238	.000	-23.8469	-12.3220
DRW	0	1	-.89731	.39916	.083	-1.8751	.0805
		2	.12071	.40314	1.000	-.8668	1.1082
	1	0	.89731	.39916	.083	-.0805	1.8751
		2	1.01802*	.40314	.041	.0305	2.0055
	2	0	-.12071	.40314	1.000	-1.1082	.8668
		1	-1.01802*	.40314	.041	-2.0055	-.0305

*. The mean difference is significant at the 0.05 level.

DW = Direct Work Rate

IW = Indirect Work Rate

DRW = Delay Due to Rework Rate

5.2.8. One-Way ANOVA Analysis for 2D Drawings, 3D Interface, and Physical Model by Dependent Variables, Students Only

Although the student sample size is not as large, a similar ANOVA output for the student sample only is highlighted in Table 5.14. Eleven currently enrolled students completed the experiment with all three model types leading to 33 data points. The full SPSS output is reported in Appendix J.

Table 5.14 ANOVA Results: Model Type by Dependent Variables, students only

	Model Type by Dependent Variables					
Dependent Variables	**Mean**	**N**	**df**	**F**	**p**	**η^2**
Time to Completion	10.13	33	30	1.61	0.218	0.097
Composite Workload	29.47	33	30	0.56	0.578	0.036
Direct Work Rate	76.65	33	30	12.29*	0.00	0.450
Rework Rate	4.09	33	30	0.78	0.467	0.050

*significant above 95%

Direct work rate is the only dependent variable with a statistically significant difference among the treatment group at the 95% confidence level. Table 5.15 compares the means of each model type against the dependent variables for the students only. Figures 5.17, 5.18, 5.19, and 5.20 present the means comparison in graphical form with percent differences from the poorest performing model type for each dependent variable.

Table 5.15 Comparison of means of information format by dependent variables, students only

Model Type	Time to Completion (minutes)		Composite Workload (0-100)		Direct Work Rate (%)		Rework Rate (%)	
	Mean	Overall Mean	Mean	Overall Mean	Mean	Overall Mean	Mean	Overall Mean
2D Drawings (n = 11)	10.99	10.13	32.88	29.47	72.32	76.65	5.50	4.09
3D Interface (n = 11)	10.35		29.39		69.58		4.16	
Physical Model (n = 11)	9.06		26.14		88.05		2.62	

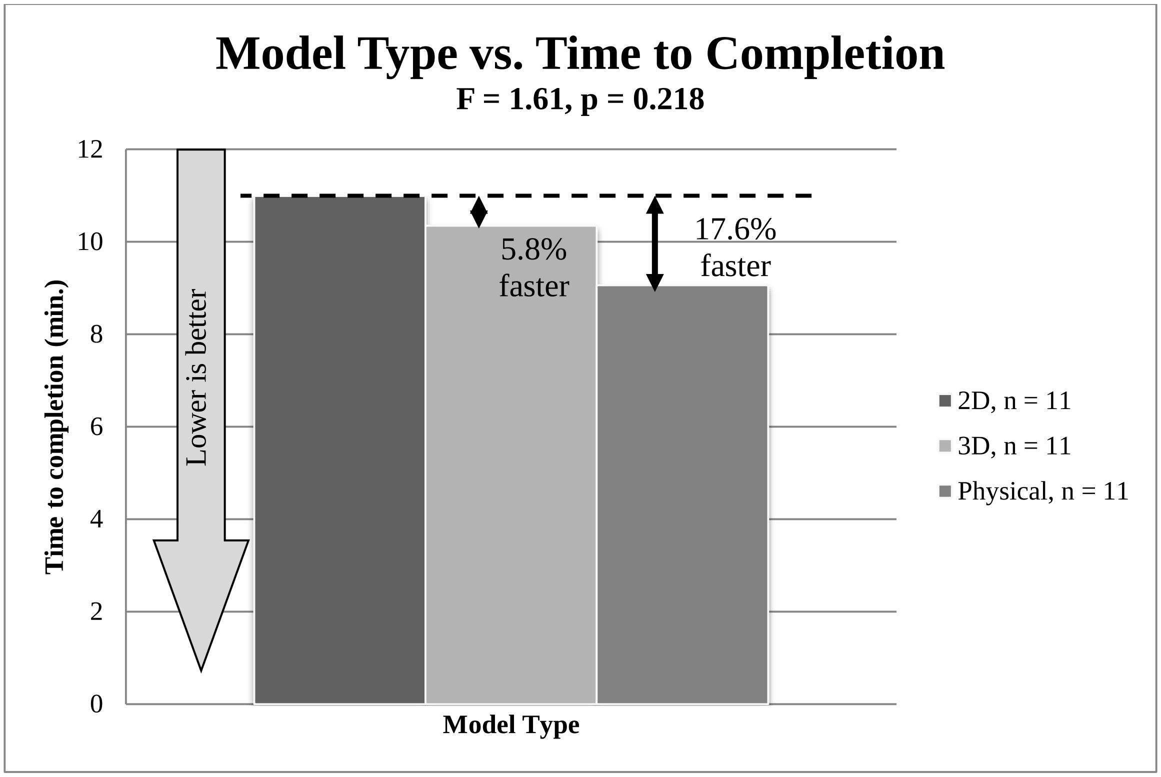

Figure 5.17 Model type versus time to completion, students only

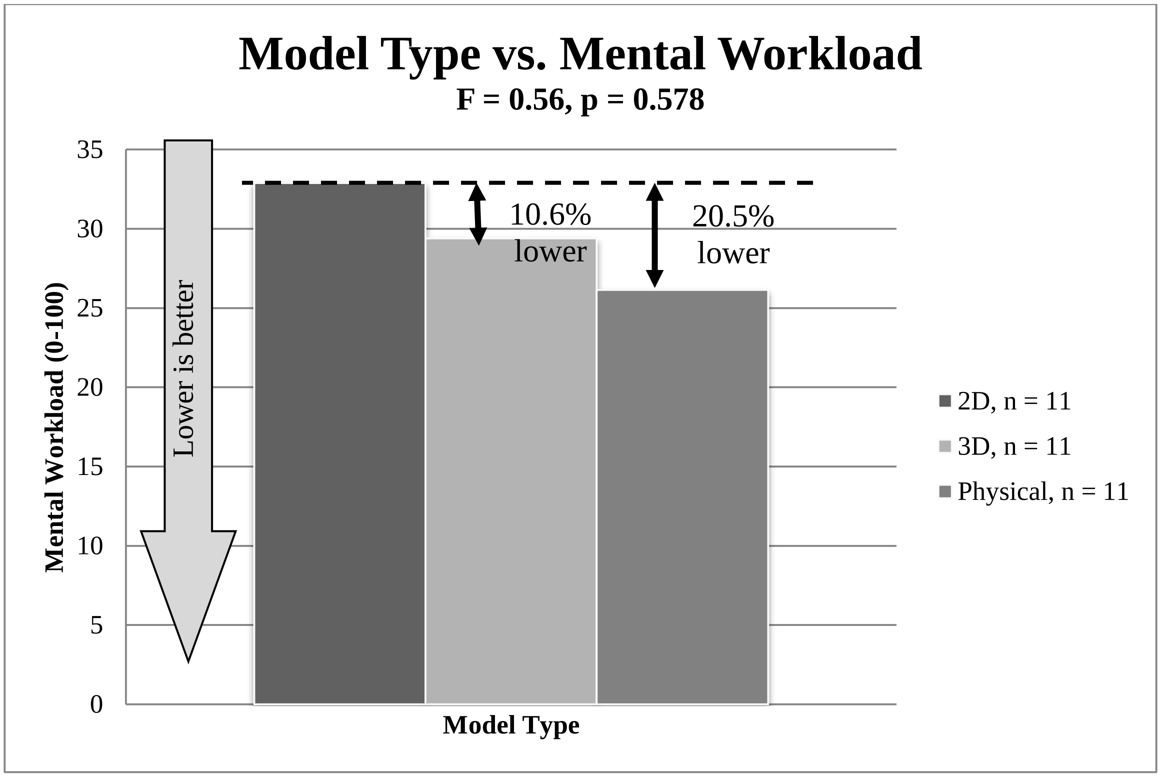

Figure 5.18 Model type versus composite mental workload, students only

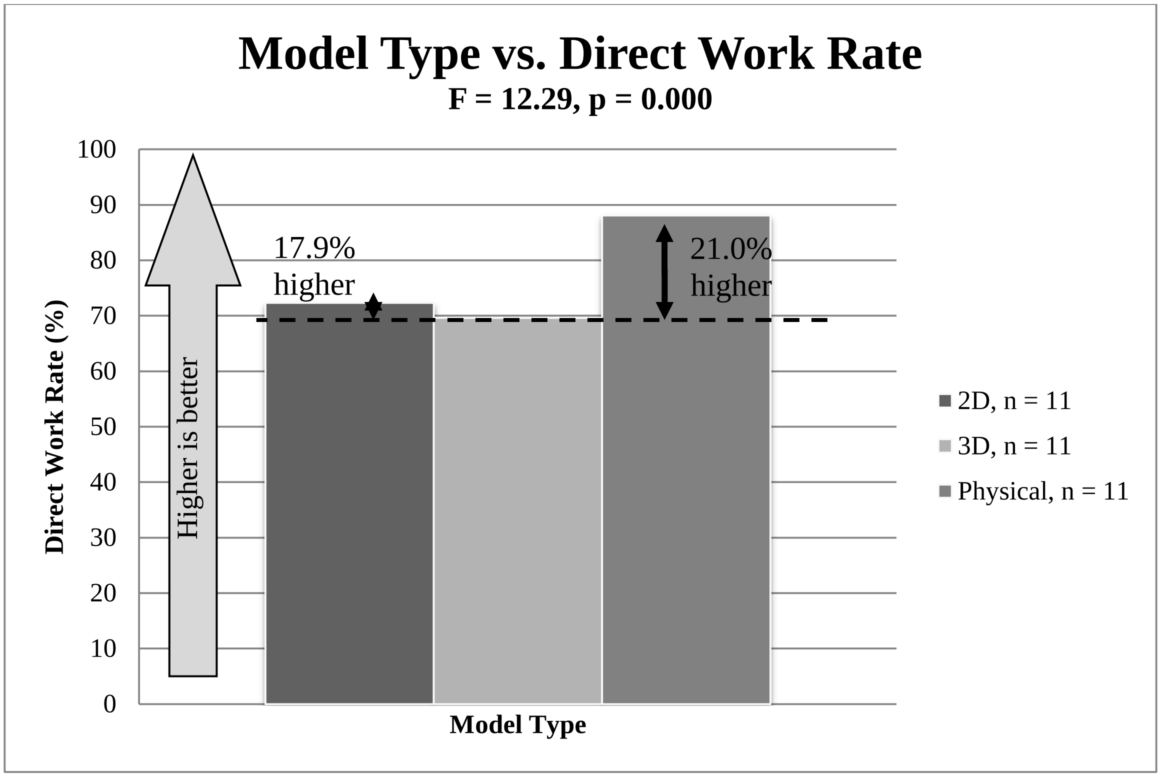

Figure 5.19 Model type versus direct work rate, students only

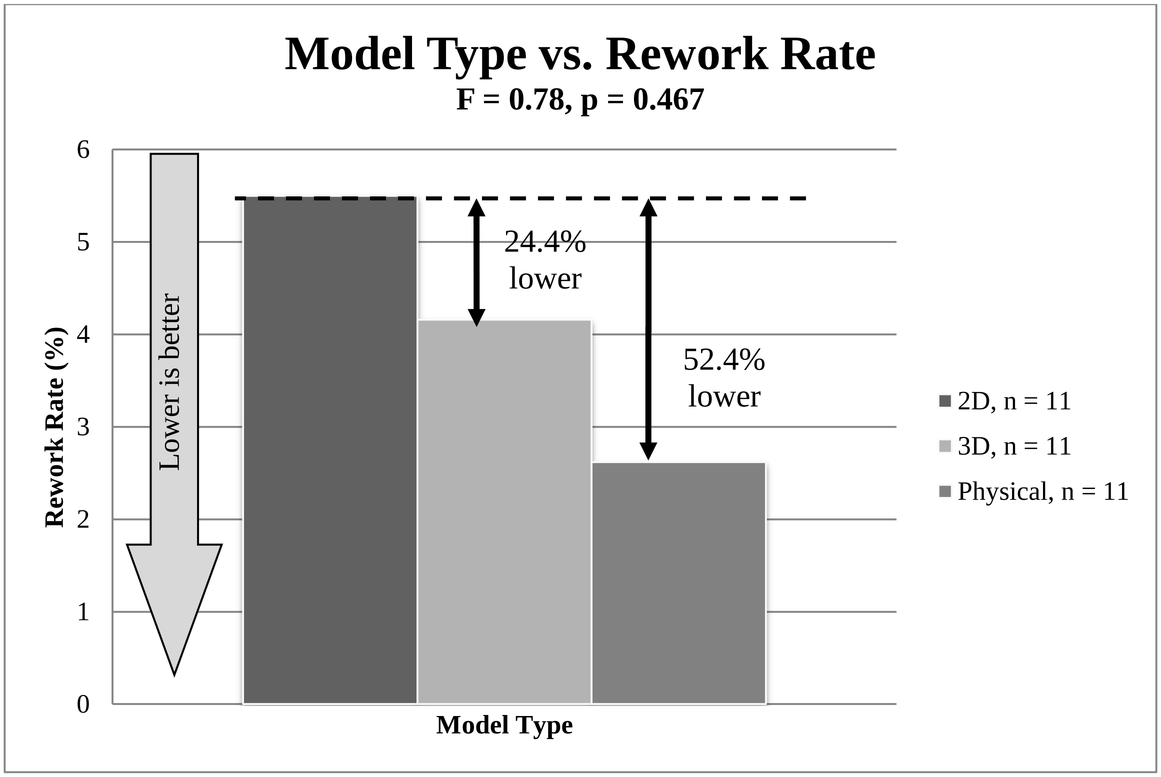

Figure 5.20 Model type versus rework rate, students only

Overall, use of the physical model outperforms the alternatives in all dependent variables. In the direct work category that is statistically different, the physical model yields 22% more efficient time than the 2D drawings and 27% more efficient work than the 3D computer model. A closer look at the data in the coming sections will help structure the significant findings and recommendations.

5.2.9. Post-Hoc Analysis for Students

Investigating the ANOVA further, the Bonferroni method is applied to the statistically significant dependent variables from the ANOVA models. Table 5.16 presents the results. The direct and indirect work rates were the only two dependent variables with a significant difference between the information formats. Use of the physical model to complete the task resulted in a 15.7% and 18.5% increase in the direct work rate compared to use of the 2D drawings and 3D computer model respectively. Conversely, use of the physical model reduced the indirect work rate by 12.9% and 15.6% compared to the 2D drawings and 3D computer model respectively.

Table 5.16 Bonferroni post-hoc analysis, students only

Multiple Comparisons

Bonferroni

Dependent Variable	(I) Model	(J) Model	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
DW	0	1	2.73727	4.02016	1.000	-7.4568	12.9314
		2	-15.72818*	4.02016	.001	-25.9223	-5.5341
	1	0	-2.73727	4.02016	1.000	-12.9314	7.4568
		2	-18.46545*	4.02016	.000	-28.6595	-8.2714
	2	0	15.72818*	4.02016	.001	5.5341	25.9223
		1	18.46545*	4.02016	.000	8.2714	28.6595
IW	0	1	-2.72636	3.45399	1.000	-11.4848	6.0321
		2	12.85091*	3.45399	.002	4.0925	21.6093
	1	0	2.72636	3.45399	1.000	-6.0321	11.4848
		2	15.57727*	3.45399	.000	6.8188	24.3357
	2	0	-12.85091*	3.45399	.002	-21.6093	-4.0925
		1	-15.57727*	3.45399	.000	-24.3357	-6.8188

*. The mean difference is significant at the 0.05 level.

DW = Direct Work Rate

IW = Indirect Work Rate

DRW = Delay Due to Rework Rate

5.2.10.Multiple Linear Regression Analysis, All Subjects

With key variables identified as the time to complete the exercise, composite workload, direct work rates, and rework rates, a multiple linear regression model to describe interactions will provide a better understanding of these key variables. Table 5.18 reports the findings from the multiple linear regression models for all subjects based on the key variables functioning as the independent variable in the model. Refer to Table 5.17 for variable names and descriptions. In Table 5.18, equation A is representative of a multiple linear regression model with time to completion as a dependent variable, equation B has composite workload as a dependent variable, equation C uses direct work rate as the dependent variable, and finally, equation D has rework rate as the dependent variable. A full SPSS output is included in Appendix K.

Table 5.17 Regression model variable names and descriptions

Variable Identifier	Variable Name	Description
Age	Age	Age of subject
Gender	Gender	Gender of subject (0 – male, 1 – female)
Exp	Years of experience	Years of experience in industry requiring drawing interpretation
Ref	Drawing Reference Frequency	How frequent subject references design of construction drawings in their work (5 point Likert scale)
CHrs	Course Hours	Number of coursework hours completed (students only)
CAD	CAD Experience	Experience in computer aided design (CAD) (0 – low, 1 – high)
TwoD	2D Drawings	Dummy variable for use of 2D drawings to complete the test (0 – not 2D, 1 – used 2D)
ThrD	3D Interface	Dummy variable for use of 3D interface to complete the test (0 – not 3D, 1 – used 3D)
Time	Time	Time to complete the test (minutes)
Seq1	Sequence of Completion	Completed 2D, 3D, and then physical model in order (0 – not sequence 1, 1 – used sequence 1)
Seq2	Sequence of Completion	Completed 3D, physical, and then 2D model in order (0 – not sequence 2, 1 – used sequence 2)
Seq3	Sequence of Completion	Completed physical, 2D, and then 3D model in order (0 – not sequence 3, 1 – used sequence 3)
Seq4	Sequence of Completion	Completed 2D, physical, and then 3D model in order (0 – not sequence 4, 1 – used sequence 4)
Seq5	Sequence of Completion	Completed 3D, 2D, and then physical model in order (0 – not sequence 5, 1 – used sequence 5)

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Variable Identifier	**Variable Name**	**Description**
Comp	Composite Workload*	Measure of the total amount of workload required to complete the task. (0-100)
MD	Mental Demand	How much mental and perceptual activity was required? Was the task easy or demanding, simple or complex, exacting or forgiving? (0-100)
PD	Physical Demand	How much physical activity was required? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious? (0-100)
TD	Temporal Demand	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic? (0-100)
OP	Operator Performance	How successful do you think you were in accomplishing the goals of the task set by the experimenter? How satisfied were you with your performance in accomplishing these goals? (0-100)
EF	Effort	How hard did you have to work (mentally and physically) to accomplish your level of performance? (0-100)
FR	Frustration	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task? (0-100)
CR	2D Spatial Orientation Performance	Card Rotations Test, ability to mentally rotate and understand 2D information. (%)
CC	3D Spatial Orientation Performance	Cube Comparisons Test, ability to mentally rotate and understand 3D information. (%)

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Variable Identifier	**Variable Name**	**Description**
DW	Direct Work Percentage*	% of time spent on physically building of the model towards the final product
IW	Indirect Work Percentage	% of time spent towards the end result of the final product that is not physically building the model (i.e. manipulating the information delivery format, planning action, gaining familiarity with the model pieces)
RW	Rework Percentage*	% of time spent disassembling or reassembling of a previously built portion of the model
DRW	Delay Due to Rework Percentage	% of time spent reprocessing the information delivery medium after rework occurs
TwoDPIF	2D Preferred Format	2D drawings are the preferred information format for experiment (0 – 2D not preferred, 1 – 2D preferred)
ThrDPIF	3D Preferred Format	3D interface is the preferred information format for experiment (0 – 3D not preferred, 1 – 3D preferred)
SES2D	Steel Erection Sequence	2D drawings are the preferred information format for planning steel erection sequence (0 – 2D not preferred, 1 – 2D preferred)
SES3D	Steel Erection Sequence	3D interface is the preferred information format for planning steel erection sequence (0 – 3D not preferred, 1 – 3D preferred)
CSP2D	Concrete Slab Placement	2D drawings are the preferred information format for calculating quantity of concrete necessary for a slab placement (0 – 2D not preferred, 1 – 2D preferred)
CSP3D	Concrete Slab Placement	3D interface is the preferred information format for calculating quantity of concrete necessary for a slab placement (0 – 3D not preferred, 1 – 3D preferred)

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Variable Identifier	**Variable Name**	**Description**
MEP2D	MEP Run Coordination	2D drawings are the preferred information format for coordinating piping installations being mindful of access space (0 – 2D not preferred, 1 – 2D preferred)
MEP3D	MEP Run Coordination	3D interface is the preferred information format for coordinating piping installations being mindful of access space (0 – 3D not preferred, 1 – 3D preferred)
CFQ2D	Cut/Fill Quantities	2D drawings are the preferred information format for calculating amount of cut and fill for earthwork operations (0 – 2D not preferred, 1 – 2D preferred)
CFQ3D	Cut/Fill Quantities	3D interface is the preferred information format for calculating amount of cut and fill for earthwork operations (0 – 3D not preferred, 1 – 3D preferred)
MC	Model Comparison	Is this new drawing set the same model as the one completed in the experiment? (0 – no, 1 – yes)
* Dependent variables		

Table 5.18 Multiple linear regression results, all subjects

Eqn	Const	Independent Variables													
		Age	Gender	Exp	Ref	CHrs	CAD	TwoD	ThrD	Time	Seq1	Seq2	Seq3	Seq4	Seq5
A	5.15 (1.20)	0.11 (1.37)	1.74 (0.94)	-0.15 (-1.69)	0.04 (0.17)	-0.01 (-0.17)	-0.37 (-0.21)	-0.8 (-0.12)	-0.61 (-0.94)	N/A	0.64 (0.36)	-0.40 (-0.18)	0.57 (0.36)	1.74 (1.03)	-0.19 (-0.18)
B	-1.27 (-0.68)	0.00 (0.02)	1.07 (1.35)	-0.03 (-0.76)	0.04 (0.46)	0.00 (0.03)	-0.40 (-0.53)	-0.04 (-0.12)	-0.38 (-1.35)	-0.00 (-0.04)	-1.29 (-1.73)	-1.26 (-1.33)	0.06 (0.08)	-0.06 (-0.08)	-0.05 (-0.10)
C	99.32 (358.75)	0.02 (3.59)	0.19 (1.64)	-0.01 (-2.04)	-0.01 (-0.93)	0.00 (1.81)	-0.18 (-1.64)	0.06 (1.38)	0.02 (0.55)	-0.03 (-3.49)	0.16 (1.42)	0.31 (2.20)	0.33 (3.31)	0.46 (4.25)	0.16 (2.28)
D	100.05 (241.25)	0.02 (3.54)	0.19 (1.62)	-0.01 (-1.98)	-0.01 (-0.95)	0.00 (1.79)	-0.18 (-1.61)	0.06 (1.43)	0.02 (0.56)	-0.03 (-3.39)	0.16 (1.41)	0.32 (2.20)	0.34 (3.31)	0.46 (4.19)	0.16 (2.31)

t-values shown in parenthesis
N=89

Eqn	Independent Variables												
	Comp	MD	PD	TD	OP	EF	FR	CR	CC	DW	IW	RW	DRW
A	-0.01 (-0.04)	0.05 (0.82)	0.02 (0.29)	-0.01 (-0.05)	-0.01 (-0.23)	0.03 (0.49)	-0.01 (-0.05)	-0.01 (-0.76)	-0.12 (-2.03)	Excl	0.09 (3.21)	0.16 (3.16)	0.32 (1.22)
B	N/A	0.16 (14.22)	0.18 (19.54)	0.17 (21.23)	0.14 (14.35)	0.17 (16.53)	0.17 (19.57)	0.01 (2.27)	-0.04 (-1.53)	Excl	0.02 (1.44)	0.02 (0.74)	0.14 (1.20)
C	-0.02 (-0.87)	0.01 (1.56)	0.00 (0.12)	0.00 (0.48)	0.00 (0.91)	0.00 (0.06)	0.01 (1.94)	-0.00 (-1.65)	0.01 (1.75)	N/A	-1.00 (-516)	-1.00 (-282)	-1.07 (-63)
D	-0.02 (-0.85)	0.01 (1.53)	0.00 (0.11)	0.00 (0.46)	0.00 (0.89)	0.00 (0.03)	0.01 (1.94)	-0.00 (-1.64)	0.01 (1.74)	-1.01 (-282)	-1.00 (-287)	N/A	-1.08 (-56.07)

t-values shown in parenthesis
N=89

Eqn	Independent Variables												F	R^2	Adj. R^2
	TwoDP IF	ThrD PIF	SES 2D	SES 3D	CSP 2D	CSP 3D	MEP 2D	MEP 3D	CFQ 2D	CFQ 3D	MC				
A	-0.42 (-0.31)	-0.16 (-0.11)	1.43 (0.81)	0.32 (0.29)	Excl	-0.52 (-0.46)	-1.79 (-1.11)	0.90 (0.61)	Excl	1.01 (1.19)	-1.38 (-1.31)		5.26	0.765	0.620
B	0.78 (1.35)	0.65 (1.08)	0.41 (0.53)	-0.10 (-0.20)	Excl	0.31 (0.63)	0.38 (0.54)	0.50 (0.78)	Excl	0.50 (1.38)	0.23 (0.50)		724.78	0.998	0.996
C	0.16 (1.83)	0.27 (3.03)	0.20 (1.76)	0.03 (0.38)	Excl	-0.17 (-2.36)	-0.25 (-2.38)	0.12 (1.26)	Excl	0.08 (1.53)	0.11 (1.64)		29530.92	1.000	1.000
D	0.16 (1.81)	0.27 (3.01)	0.20 (1.74)	0.03 (0.37)	Excl	-0.17 (-2.32)	-0.25 (-2.37)	0.12 (1.21)	Excl	0.08 (1.46)	0.11 (1.63)		7091.47	1.000	1.000

t-values shown in parenthesis
N=89

Several outcomes are apparent from the results in Table 5.18. First, all equations tested have a high "goodness of fit" given by the r^2 and adjusted r^2 values, with all being higher than 0.62. This means that all models are able to account for greater than 62% of the variability in the dependent variable. In the direct work and rework rate models, 100% of the variability is accounted for in the inclusion of the variables listed.

However, in all of the models, there were variables that were excluded from the analysis due to an issue with multicollinearity. Multicollinearity is a frequent issue in multiple regression analysis where explanatory variables are correlated with one another, resulting in poor least squares estimates of the regression coefficients (Dielman, 2005). There are several ways to identify the presence of multicollinearity in a regression model including pairwise correlations, a large F statistic with small t statistics, and variance inflation factors (VIFs). VIFs allow for a measure of the strength of the relationship between each explanatory variable and all the other explanatory variables, which is a characteristic that is not available from pairwise correlations and F and t statistics. An individual explanatory variable VIF greater than ten indicates that multicollinearity may be a factor in the model, and thus, should be eliminated from the analysis. While SPSS eliminates certain variables from the analysis as is seen in Table 5.18. It does not automatically run multicollinearity diagnostics and remove variables based on the outcomes. This has to be run separate, and Table 5.19 reports on individual VIF factors for each equation as previous.

Before significant conclusions are made from the regression models, the highly correlated independent variables must be removed and the analysis must be rerun.

Without this step, the full regression model is weakened which weakens the reported results.

Table 5.19 Variance inflation factors (VIF) for regression model, all subjects

VIF	Equation			
Variable Name	A	B	C	D
Age	14.60	15.09	15.09	15.18
Gender	5.74	5.64	5.83	5.84
Exp	19.57	20.37	20.58	20.66
Ref	5.01	5.00	5.02	5.01
CHrs	16.65	16.66	16.66	16.67
CAD	14.08	14.02	14.10	14.12
TwoD	1.87	1.87	1.87	1.86
ThrD	1.78	1.75	1.81	1.81
Time	N/A	4.25	4.25	4.30
Seq1	8.22	7.81	8.24	8.24
Seq2	13.03	12.64	13.04	13.04
Seq3	6.46	6.48	6.48	6.48
Seq4	7.44	7.58	7.58	7.63
Seq5	3.03	3.03	3.03	3.02
Comp	449.03	N/A	449	449
MD	27.61	5.97	27.94	27.98
PD	23.88	3.01	23.92	23.92
TD	35.79	3.89	35.79	35.80
OP	16.45	3.47	16.46	16.47
EF	34.47	5.80	34.62	34.62
FR	26.79	3.36	26.80	26.80
CR	2.77	2.56	2.80	2.80
CC	6.45	6.65	6.94	6.94
DW	15625	18878	N/A	13.03
IW	1.82	2.08	2.16	6.97
RW	2.65	3.10	3.13	N/A
DRW	2.70	2.70	2.78	3.44
TwoDPIF	8.54	8.28	8.56	8.57
ThrDPIF	5.16	5.05	5.16	5.17
SES2D	8.05	8.11	8.15	8.16
SES3D	5.49	5.50	5.50	5.50
CSP3D	5.83	5.81	5.85	5.87
MEP2D	5.64	5.74	5.77	5.78
MEP3D	7.28	7.24	7.32	7.34
CFQ3D	3.27	3.24	3.35	3.36
MC	4.02	4.13	4.14	4.15

With many variables in all equations having VIFs greater than 10, there is significant multicollinearity in the regression models. Prior to reporting significant findings, the same regression analysis is completed while removing the highly correlated independent variables and reported in Table 5.20. Independent variables from a step-wise regression analysis with a p-value threshold of 0.05, as reported in Table 5.20, and have VIFs less than 10 and findings can then be deduced.

When time to completion is the dependent variable, the statistically significant contributors that influence the dependent variable are the level of computer aided drawing experience (CAD), mental demand, cube comparisons score, direct work rate, delay due to rework rate, and the model comparison score. Subjects with a high level of CAD experience completed the experiment 1.42 minutes longer than subjects with a low level of CAD experience. Individuals that found the task to be mentally demanding took longer to complete the experiment. For every unit increase in mental demand, the time to complete the experiment increased by 0.06 minutes (As subjects' cube comparison score increases by one unit, the time to complete the task decreases by 0.06 minutes (3.6 seconds). This is a likely scenario, especially in the 3D computer and physical model, as a higher cube comparisons score indicates a stronger ability to rotate 3D images. With a better innate ability to mentally rotate 3D images, the individuals should be able to perform the task faster. The direct work rate and delay due to rework rate are indirectly and directly proportional to the time to complete respectively. That is, as the direct work rate increases by one unit, the time to complete decreases by 0.10 minutes (6 seconds). As the delay due to rework rate increases by one percent, the time to complete the task also increases by a factor of 0.51 minutes (31 seconds). If subjects spend more time in preparation or correction of work, then the time to complete the task should likewise increase. Finally, when subjects believed the test model was the same as the post-test model, the time to complete the task decreases by 1.26 minutes or 1 minute and 16 seconds. This is also a logical finding, since the models to compare are different. By responding that the models are the same, the individuals did not process and retain the mental image of the model building task, indicating that they may not possess the spatial abilities necessary to perform the task as quickly as possible.

In the model for equation B (composite workload as dependent variable), the significant explanatory variables are mental demand, physical demand, temporal demand, operator performance, effort, frustration, and the card rotations score. These variables are essentially the outcomes from the mental workload component and the NASA-rTLX worksheet as well as the card rotations test. The regression coefficients show that for every unit increase in mental demand, physical demand, temporal demand, operator performance, effort, and frustration, there is an increase in the range of 0.14-0.18 in the composite workload score. The measures from the NASA-rTLX categories should trend together as each increase in demand ultimately increases the composite score. In addition, the card rotations score is directly proportional to the composite workload score.

The direct work rate equation has several different statistically significant explanatory variables that include time to complete, sequence 4 (2D, physical, and then 3D), card rotations score, indirect work rate, rework rate, and delay due to rework rate. There is an indirectly proportional relationship between the direct work rate and time to complete, card rotations score, indirect work rate, and delay due to rework rate. Lower time to complete, indirect work rates, and delay due to rework rate indicate better performance and a higher direct work rate. Sequence 4 is the only significant directly proportional explanatory variable. When the subjects used sequence four, there was a statistically significant improvement (1.5% improvement) in the direct work rate.

Finally, the rework rate equation has time to complete, sequence 4, indirect work rate, delay due to rework rate, and the response to which information format would be used in calculating earthwork quantities as statistically significant explanatory variables. As time to complete the study increases by one minute, the rework rate increases by a percent. This relationship is logical, in that as more time is spent identifying and correcting errors, the longer it takes to complete the task correctly. If subjects complete the task using sequence 4 (2D, physical, and then 3D), the rework rate decreases 6.12%. Similar to the previous model, it appears that sequence 4 yields the highest direct work rate and lowest rework rate at a significant level. A one unit increase in the indirect work rate and delay due to rework results in a change of the rework rate by -0.15% and 2.21% respectively. As subjects invest more time studying the information format and preparing for the task, the fewer mistakes are made. In addition, as more errors are made, there is more time spent on understanding where mistakes are made and "re-understanding" the proper information. Finally, subjects that chose to use a 3D computer model to calculate the quantity of earthwork cut and fill necessary had 4.71% lower rework rates.

Table 5.20 Step-wise regression analysis results after multicollinearity correction, all subjects

Eqn	Const	Independent Variables									
		CAD	MD	CC	DW	DRW	MC		F	R^2	Adj. R^2
A	16.834 (9.407)	1.416 (2.976)	0.059 (5.367)	-0.058 (-4.839)	-0.094 (-4.693)	0.507 (2.697)	-1.259 (-2.063)		30.101	0.685	0.662

Eqn	Const	Independent Variables												
		EF	FR	TD	PD	OP	MD	MC	CR	DW		F	R^2	Adj. R^2
B	0.787 (1.132)	0.170 (21.665)	0.174 (29.911)	0.169 (35.689)	0.168 (26.910)	0.137 (22.985)	0.162 (20.434)	0.703 (2.984)	0.012 (2.683)	-0.019 (-2.584)		>1000	0.997	0.997

Eqn	Const	Independent Variables							
		Time	IW	RW	DRW		F	R^2	Adj. R^2
C	100.19 (1622)	-0.022 (-3.194)	-0.998 (-554)	-0.994 (-322)	-1.066 (-70.94)		>1000	1.000	1.000

Eqn	Const	Independent Variables							
		Time	DW	IW	DRW		F	R^2	Adj. R^2
D	100.71 (302)	-0.021 (-3.061)	-1.005 (-322)	-1.004 (-312)	-1.071 (-64.32)		>1000	1.000	1.000

t-values shown in parenthesis
N=89

5.2.11.Multiple Linear Regression Analysis, Practitioners Only

While interesting outcomes result in the regression analysis for all subjects, the primary results come from the two distinct sample groups, practitioners and students. The same analyses are repeated from the previous section in Table 5.21, 5.22, and Appendix L. The regression summary including coefficients, t, F, r^2, and adjusted r^2 values are seen in Table 5.15 with a full SPSS output located in Appendix L. In addition, Table 5.22 reports the VIF variables for the regressions. Similar to the previous tables, equation A represents a multiple linear regression with time to completion as the dependent variable. Equations B, C, and D use composite workload, direct work rate, and rework rate as dependents variables respectively.

Table 5.21 Regression analysis results, practitioners only

Eqn	Const	Independent Variables													
		Age	Gender	Exp	Ref	CHrs	CAD	TwoD	ThrD	Time	Seq1	Seq2	Seq3	Seq4	Seq5
A	6.15 (1.11)	0.15 (1.21)	2.14 (0.64)	-0.27 (-2.01)	0.09 (0.29)	-0.01 (-0.55)	0.37 (0.20)	-0.14 (-0.19)	-0.59 (-0.74)	N/A	1.76 (0.72)	-1.75 (-0.56)	0.32 (0.17)	1.90 (0.90)	-0.71 (-0.60)
B	-2.09 (-0.82)	0.02 (0.33)	-0.12 (-0.08)	-0.01 (-0.13)	-0.08 (-0.59)	0.00 (0.26)	-0.37 (-0.44)	-0.01 (-0.02)	-0.37 (-1.04)	0.01 (0.13)	-0.85 (-0.77)	0.08 (0.06)	0.40 (0.47)	0.26 (0.26)	0.14 (0.25)
C	99.27 (336)	0.01 (0.95)	0.62 (3.47)	-0.00 (-0.14)	0.02 (1.30)	0.00 (1.41)	-0.21 (-2.13)	0.06 (1.53)	0.03 (0.68)	-0.02 (-2.97)	-0.11 (-0.82)	0.02 (0.14)	0.28 (2.82)	0.27 (2.39)	0.18 (2.88)
D	99.91 (233)	0.01 (0.92)	0.62 (3.47)	-0.00 (-0.09)	0.02 (1.29)	0.00 (1.41)	-0.21 (-2.12)	0.06 (1.57)	0.03 (0.68)	-0.02 (-2.90)	-0.11 (-0.85)	0.02 (0.14)	0.28 (2.82)	0.27 (2.36)	0.18 (2.92)

t-values shown in parenthesis
N=77

Eqn	Independent Variables												
	Comp	MD	PD	TD	OP	EF	FR	CR	CC	DW	IW	RW	DRW
A	0.04 (0.13)	0.03 (0.50)	-0.01 (-0.22)	-0.02 (-0.33)	-0.02 (-0.41)	0.03 (0.44)	-0.02 (-0.38)	-0.02 (-1.29)	-0.15 (-2.11)	Excl	0.09 (2.86)	0.19 (3.49)	0.47 (1.32)
B	N/A	0.16 (11.94)	0.18 (14.25)	0.17 (16.08)	0.14 (10.04)	0.17 (13.77)	0.18 (17.39)	0.01 (2.37)	-0.03 (-0.76)	Excl	0.02 (1.04)	0.01 (0.35)	0.23 (1.39)
C	-0.00 (-0.10)	0.00 (0.89)	-0.00 (-0.73)	0.00 (-0.07)	0.00 (1.13)	-0.00 (-0.47)	0.00 (1.12)	-0.00 (-2.07)	0.01 (1.71)	Excl	-1.00 (-529)	-0.99 (-308)	-1.12 (-58.5)
D	-0.00 (-0.09)	0.00 (0.88)	-0.00 (-0.74)	0.00 (-0.07)	0.00 (1.13)	-0.00 (-0.49)	0.00 (1.12)	-0.00 (-2.05)	0.01 (1.72)	-1.01 (-308)	-1.00 (-315)	N/A	-1.13 (-54.8)

t-values shown in parenthesis
N=77

Eqn	Independent Variables												F	R^2	Adj. R^2
	TwoDP IF	ThrD PIF	SES 2D	SES 3D	CSP 2D	CSP 3D	MEP 2D	MEP 3D	CFQ 2D	CFQ 3D	MC				
A	0.38 (0.22)	-0.01 (-0.01)	-0.10 (-0.04)	0.24 (0.16)	0.99 (0.70)	Excl	-1.35 (-0.56)	1.10 (0.52)	Excl	1.46 (1.61)	-2.03 (-1.45)		4.826	0.792	0.628
B	0.29 (0.37)	0.53 (0.76)	0.96 (0.80)	0.25 (0.37)	0.03 (0.04)	Excl	-0.26 (-0.23)	0.16 (0.16)	Excl	0.48 (1.15)	0.65 (1.01)		535.118	0.998	0.996
C	0.08 (0.84)	0.25 (3.08)	0.34 (2.47)	0.00 (0.03)	0.06 (0.82)	Excl	-0.04 (-0.33)	0.18 (1.65)	Excl	0.04 (0.81)	0.04 (0.49)		35660	1.000	1.000
D	0.08 (0.82)	0.25 (3.06)	0.35 (2.48)	0.00 (0.03)	Excl	-0.06 (-0.80)	-0.04 (-0.32)	0.18 (1.63)	-0.04 (-0.75)	Excl	0.04 (0.49)		8993	1.000	1.000

t-values shown in parenthesis
N=77

Table 5.22 Variance inflation factors (VIF) for regression model, practitioners only

VIF	Equation			
Variable Name	A	B	C	D
Age	28.04	28.91	28.98	29.02
Gender	12.35	12.46	12.47	12.48
Exp	31.07	33.98	34.00	34.01
Ref	8.10	8.05	8.11	8.12
CHrs	16.77	16.86	16.89	16.89
CAD	11.85	11.81	11.86	11.88
TwoD	2.04	2.04	2.04	2.04
ThrD	2.16	2.13	2.19	2.19
Time	N/A	4.81	4.82	4.86
Seq1	9.28	9.26	9.39	9.38
Seq2	23.39	23.56	23.56	23.56
Seq3	8.62	8.58	8.62	8.61
Seq4	7.08	7.20	7.21	7.24
Seq5	3.29	3.32	3.32	3.31
Comp	424	N/A	424.00	424.00
MD	28.18	6.57	28.34	28.35
PD	24.72	4.32	24.74	24.74
TD	33.90	4.84	33.98	33.98
OP	15.79	4.74	15.85	15.86
EF	32.27	5.99	32.42	32.40
FR	28.10	3.51	28.20	28.18
CR	3.35	3.08	3.48	3.49
CC	7.16	7.79	7.90	7.89
DW	24500	29700	N/A	13.14
IW	2.12	2.47	2.53	7.10
RW	2.58	3.30	3.31	N/A
DRW	2.77	2.76	2.88	3.29
TwoDPIF	11.85	11.83	11.86	11.87
ThrDPIF	4.79	4.73	4.79	4.80
SES2D	16.71	16.47	16.71	16.70
SES3D	8.66	8.64	8.66	8.66
CSP2D	7.29	7.37	7.37	7.37
MEP2D	11.55	11.62	11.63	11.63
MEP3D	12.29	12.36	12.36	12.38
CFQ3D	3.08	3.16	3.26	3.27
MC	5.88	6.02	6.17	6.17

The full regression model, again, has significant multicollinearity issues. Therefore, certain variables must be eliminated and the analysis completed again, which is reported through a step-wise regression in Table 5.23. This data provides a look into descriptors of practitioners' performance in regards to the dependent variables; time to completion, composite workload, direct work rate, and rework rate.

In equation A (time to complete as dependent variable), the direct work rate, cube comparisons score, gender, delay due to rework, and mental demand are the statistically significant predictors for time to completion. Higher direct work rates for practitioners led to faster completion times, as would be expected. A one percent increase in the direct work rate resulted in 0.10 minute (6 second) faster completion speeds. A higher cube comparisons score results in faster completion as this indicates that practitioners are better inclined to mentally rotate 3D objects. Gender played a strong role with the practitioner sample, where females completed the experiment 2.93 minutes faster than males. While this is a significant figure, its impact should be viewed as skeptically, as only one female practitioner completed the experiment. Higher delay due to rework rates increases the time to complete the task by 0.65 minutes as this measure does not result in direct building of the correct model. Finally, an increase in mental demand increases the time to complete the building model. As practitioners found the task to be more mentally challenging, the required time to complete the experiment increased.

Model B, composite workload as the dependent variable, has the six sub-categories from the NASA-rTLX, the response to the model comparison question, the card rotations score, and delay due to rework rate as significant predictors of the dependent variable. The sub-categories increase the composite workload between 0.13-0.18 for each unit increase. The sub-categories are directly proportional to the composite workload as they are direct contributors to its outcome.

The direct work rate model, equation C, statistically depends on the time to complete, card rotations score, indirect work rate, rework rate, delay due to rework rate, and frustration score. For every minute faster that subjects complete the test, the direct work rate increases by 0.02%. There is a negligible decrease (0.002%) in the direct work rate as individual's card rotations score increases. Conversely, there is a negligible increase (0.002%) in the direct work rate as practitioner's frustration level increases. The indirect work rate and rework rate are inversely proportional to the direct work rate and result in approximately a 1:1 change. That is, for every 1% decrease in the indirect work and rework rate, there is a 1% increase in the direct work rate. Similarly, the delay due to rework rate has an inverse relationship with the direct work rate but a slightly larger impact. Every 1% decrease in the delay due to rework rate results in a 1.13% increase in the direct work rate.

The rework rate model (Equation D) leverages the direct work rate, indirect work rate, delay due to rework rate, card rotations score, and time to complete as statistically significant descriptors. An increase in the direct, indirect, and delay due to rework rates each decrease the rework rate by about 1%. The card rotations score has a minor, but statistically significant impact on the rework rate. As the card rotations score increases by a point, the rework rate decreases by 0.003%. There are also minor impacts (decrease of 0.02% and increase of 0.002%) for a unit increase in the time to complete the task and frustration score respectively.

Table 5.23 Step-wise regression analysis results after multicollinearity correction, practitioners only

Eqn	Const	Independent Variables								
		DW	CC	Gender	DRW	MD		F	R^2	Adj. R^2
A	16.442 (8.505)	-0.097 (-4.636)	-0.033 (-3.163)	2.926 (3.187)	0.647 (2.610)	0.058 (4.726)		31.377	0.685	0.664

Eqn	Const	Independent Variables												
		EF	FR	TD	PD	OP	MD	MC	CR	DRW		F	R^2	Adj. R^2
B	-1.060 (-2.572)	0.167 (19.759)	0.177 (28.983)	0.170 (32.744)	0.167 (22.901)	0.128 (18.134)	0.168 (20.821)	0.951 (3.518)	0.016 (3.189)	0.291 (2.803)		>1000	0.997	0.997

Eqn	Const	Independent Variables									
		IW	RW	DRW	CR	Time	FR		F	R^2	Adj. R^2
C	100.274 (1355)	-0.998 (-633)	-0.996 (-378)	-1.126 (-69.639)	-0.002 (-3.687)	-0.022 (-3.507)	0.002 (3.118)		>1000	1.000	1.000

Eqn	Const	Independent Variables									
		DW	IW	DRW	CR	Time	FR		F	R^2	Adj. R^2
D	100.671 (354)	-1.004 (-378)	-1.002 (-361)	-1.130 (-65.217)	-0.003 (-3.712)	-0.021 (-3.423)	0.002 (3.149)		>1000	1.000	1.000

t-values shown in parenthesis
N=77

5.2.12.Multiple Linear Regression Analysis, Students Only

Practitioner output was presented and discussed in the previous section, which leaves the other sample group, students, to be reported. The regression summary including coefficients, *t*, *F*, r^2, and adjusted r^2 values are seen in Table 5.24 with a full SPSS output located in Appendix M. Similar to the previous tables, equation A represents a multiple linear regression with time to completion as the dependent variable. Equations B, C, and D use composite workload, direct work rate, and rework rate as dependents variables respectively. The multicollinearity reports show the existence of high levels of correlation between independent variables, as seen in the VIF values in Table 5.25. Subsequently, the variables with VIFs greater than 10 were removed, and new step-wise regression models were created in Table 5.26.

Table 5.24 Regression analysis results, students only

Eqn	Const	Independent Variables													
		Age	Gender	Exp	Ref	CHrs	CAD	TwoD	ThrD	Time	Seq1	Seq2	Seq3	Seq4	Seq5
A	13.63 (4.23)	Excl	-10.67 (-2.99)	Escl	-1.15 (-2.47)	-0.00 (-0.33)	7.56 (2.48)	0.84 (1.04)	0.74 (1.01)	N/A	5.96 (2.06)	Excl	Excl	Excl	1.77 (1.70)
B	-0.01 (-0.55)	0.00 (0.74)	0.02 (0.92)	Excl	0.00 (0.92)	Excl	Excl	0.00 (0.22)	-0.00 (-0.37)	0.00 (0.80)	-0.01 (-1.09)	Excl	Excl	Excl	-0.01 (-0.62)
C	100.00 (6524)	0.00 (0.78)	-0.01 (-0.72)	-0.00 (-1.06)	Excl	0.00 (-0.48)	0.01 (0.38)	0.00 (0.03)	0.00 (0.53)	0.00 (-0.24)	Excl	Excl	Excl	Excl	-0.00 (-0.67)
D	100.00 (2476)	0.00 (0.49)	Excl	Excl	-0.00 (-0.57)	Excl	Excl	0.00 (0.03)	0.00 (0.53)	0.00 (-0.24)	0.02 (1.08)	0.00 (0.24)	Excl	0.02 (0.62)	0.01 (0.61)

t-values shown in parenthesis
N=33

Eqn	Independent Variables												
	Comp	MD	PD	TD	OP	EF	FR	CR	CC	DW	IW	RW	DRW
A	Excl	0.03 (0.63)	-0.00 (-0.14)	0.01 (0.39)	0.05 (2.30)	-0.03 (-0.77)	0.01 (0.40)	-0.15 (-2.17)	0.56 (1.95)	Excl	0.05 (1.55)	0.11 (1.51)	-0.26 (-0.73)
B	N/A	0.17 (1313)	0.17 (2835)	0.17 (2917)	0.17 (2917)	0.17 (1372)	0.17 (2440)	0.00 (0.37)	-0.00 (-0.67)	Excl	0.00 (-2.46)	0.00 (-1.50)	0.00 (0.82)
C	0.00 (0.85)	0.00 (-0.96)	0.00 (-0.32)	0.00 (-0.57)	0.00 (-1.06)	Excl	0.00 (-0.48)	0.00 (-0.82)	0.00 (0.87)	Excl	-1.00 (-6200)	-1.00 (-2680)	-1.00 (-597)
D	Excl	0.00 (-0.94)	0.00 (1.02)	0.00 (0.51)	0.00 (-1.07)	0.00 (0.85)	0.00 (0.52)	0.00 (-0.81)	0.00 (0.87)	-1.00 (-2680)	-1.00 (-3030)	N/A	-1.00 (-508)

t-values shown in parenthesis
N=33

Eqn	Independent Variables												F	R^2	Adj. R^2
	TwoDP IF	ThrD PIF	SES 2D	SES 3D	CSP 2D	CSP 3D	MEP 2D	MEP 3D	CFQ 2D	CFQ 3D	MC				
A	Excl	-1.17 (-0.54)	-0.23 (-0.22)	Excl	Excl	Excl	Excl	Excl	Excl	-1.49 (-1.24)	4.07 (1.46)		5.26	0.931	0.754
B	Excl	0.01 (0.62)	-0.02 (-2.01)	Excl	Excl	0.00 (0.67)	Excl	-0.01 (-1.66)	Excl	Excl	-0.02 (-1.17)		>1000	1.000	1.000
C	Excl	Excl	Excl	-0.01 (-0.51)	Excl	-0.01 (-0.47)	Excl	-0.01 (-0.47)	Excl	Excl	-0.01 (-0.34)		>1000	1.000	1.000
D	Excl	0.00 (0.24)	0.01 (1.00)	Excl	Excl	-0.01 (-0.48)	Excl	Excl	Excl	Excl	0.01 (0.51)		>1000	1.000	1.000

t-values shown in parenthesis
N=33

Table 5.25 Variance inflation factors (VIF) for regression model, students only

VIF	Equation			
Variable Name	A	B	C	D
Age	Excl	Excl	Excl	18.96
Gender	36.68	104.00	Excl	46.22
Exp	Excl	Excl	Excl	Excl
Ref	67.91	156.00	20.96	84.56
CHrs	14.04	10.35	11.66	12.41
CAD	17.68	Excl	26.86	Excl
TwoD	3.18	4.83	4.83	4.83
ThrD	2.83	3.39	3.39	3.39
Time	N/A	6.40	6.40	6.40
Seq1	42.28	50.91	94.21	69.95
Seq2	Excl	Excl	Excl	Excl
Seq3	Excl	43.88	Excl	26.21
Seq4	5.36	31.21	7.25	Excl
Seq5	12.25	16.61	10.16	20.51
Comp	>1000	N/A	246.00	>1000
MD	19.44	19.44	45.90	19.44
PD	6.08	6.23	15.24	6.23
TD	9.65	9.73	26.79	9.73
OP	4.76	5.49	16.08	5.49
EF	14.07	14.10	>1000	14.10
FR	10.61	11.09	27.96	11.09
CR	76.27	103.00	103.00	103.00
CC	194.00	256.00	256.00	256.00
DW	>1000	>1000	N/A	13.85
IW	3.03	3.43	3.42	7.41
RW	3.56	4.03	4.03	N/A
DRW	6.22	6.23	6.23	7.34
TwoDPIF	Excl	Excl	168.00	Excl
ThrDPIF	19.06	58.94	13.66	22.55
SES2D	24.17	38.63	140.00	51.60
SES3D	27.39	17.14	16.12	42.01
CSP2D	31.19	Excl	22.62	Excl
CSP3D	Excl	24.29	Excl	41.03
MEP2D	16.63	Excl	16.17	31.02
MEP3D	Excl	24.98	Excl	Excl
CFQ2D	Excl	29.58	Excl	24.61
CFQ3D	11.63	Excl	24.02	Excl
MC	110.00	6.40	81.70	158.00

Table 5.26 Step-wise regression analysis results after multicollinearity correction, students only

Eqn	Const	Independent Variables						
		DW	ThrDPIF	CC		F	R^2	Adj. R^2
A	19.683 (11.926)	-0.117 (-5.720)	1.264 (2.290)	-0.024 (-2.117)		14.355	0.598	0.556

Eqn	Const	Independent Variables									
		EF	TD	PD	FR	OP	MD		F	R^2	Adj. R^2
B	0.001 (0.598)	0.167 (3302)	0.167 (8198)	0.167 (4988)	0.167 (4663)	0.167 (4441)	0.167 (3382)		>1000	0.997	0.997

Eqn	Const	Independent Variables							
		IW	RW	DRW	CC		F	R^2	Adj. R^2
C	99.993 (51726)	-1.000 (--15773)	-1.000 (-7316)	-1.000 (-2027)	0.000 (2.827)		>1000	1.000	1.000

Eqn	Const	Independent Variables					
		DRW	TwoD		F	R^2	Adj. R^2
D	1.732 (1.848)	2.355 (4.863)	3.511 (2.255)		12.622	0.457	0.421

t-values shown in parenthesis
N=33

The student sample group had several variables with high levels of multicollinearity, resulting in a smaller reduced model than the practitioners. In equation A, only the direct work rate, 3D preferred model, and cube comparisons score are significant predictors of the time to complete the model. For every one percent increase in the direct work rate, the time to complete the task decreases by 0.11 minutes or 6.6 seconds. With subjects spending more time directly building the model, that is time being effectively spent on building the model, resulting in shorter completion times. Students that preferred the 3D computer model to complete the task had 1.26 minute longer completion times. Higher cube comparison scores resulted in 0.02 minutes or 1.2 seconds short completion times.

When composite workload is the independent variable, the significant dependent variables are the six factors that compromise the NASA-rTLX measure. As effort, time demand, physical demand, frustration, performance, and mental demand increase by one unit, the composite workload increases by approximately 0.167 units for each factor.

Equation C, the direct work rate model, has significant predictors of indirect work rate, rework rate, delay due to rework, and cube comparisons score. Each has an inverse relationship with the direct work where each unit increase in indirect work, rework, or delay due to rework rate results in a one unit decrease in the direct work rate. The cube comparisons score impact was negligible (< 0.000).

Finally, the rework rate model only has delays due to rework and 2D preferred as statistically significant dependent variables. As the delay due to rework rate increases by a percent, the rework rate increases by 2.36%. This relationship is reasonable because the existence of a delay due to rework is reliant on a previous occurrence of rework. Students that preferred 2D drawings to complete the experiment had 3.51% higher rework rates indicating their lack of familiarity with the model type.

5.3. Analysis of Practitioner Preferences and Performance

5.3.1. Practitioner Preferences for Task Completion

The previous analysis shows that the subjects, both practitioners and students, performed the experiment best with the physical model, then the 2D drawings, and lastly, the 3D computer model. In the post-test questionnaire, subjects are asked which information format was preferred in the completion of the task. Figure 5.21 shows that only 39% of subjects prefer the physical model compared to 46% and 15% for the 2D drawings and 3D model respectively.

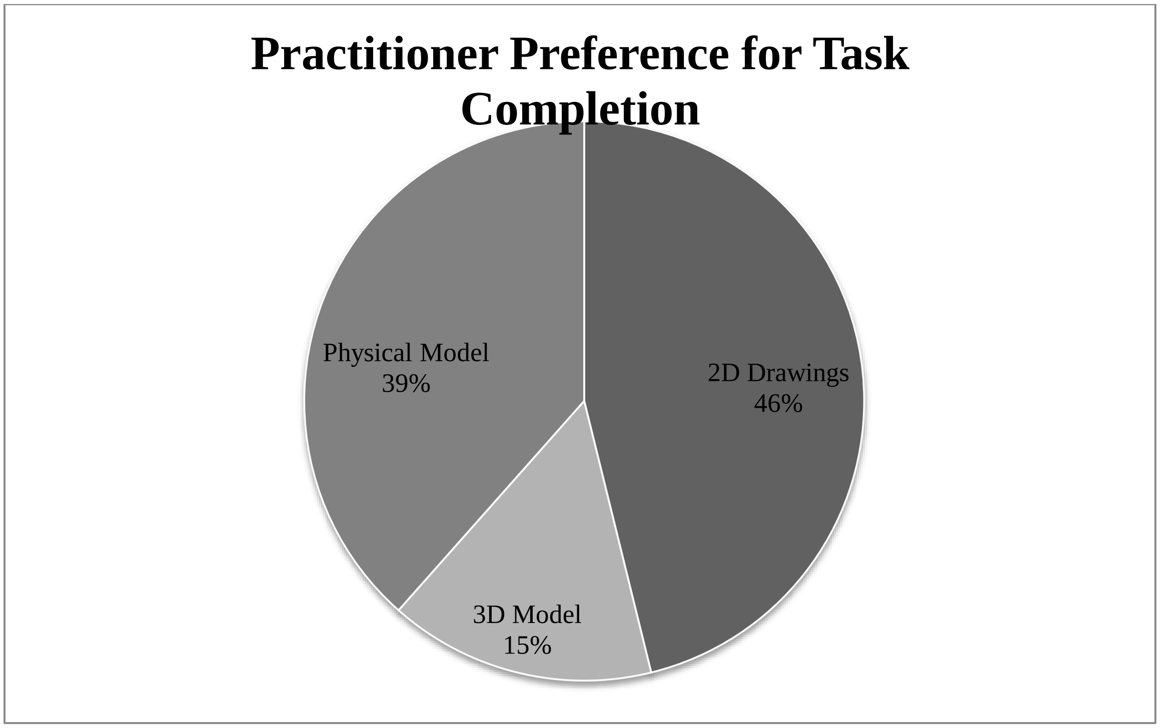


Figure 5.21 Practitioners' Preference for Task Completion

Included in the data collection for preferences was an opportunity for the subjects to provide insights into why he/she preferred a particular information format. Table 5.27

outlines some of the interesting responses by subjects as to why a certain format was preferred.

Table 5.27 Selected responses to model preferences, practitioners only

Responses from practitioners that preferred 2D drawings	Responses from practitioners that preferred a 3D computer model	Responses from practitioners that preferred a physical model
"Easy to understand"	"Agile, one-stop info source, and easily modifiable"	"Easier to build if you can see what it is supposed to look like"
"Used to reading from drawings"	"Accessibility and ease of viewing the model from any perspective without having to do much"	"Easy to figure out spatial shape in my mind"
"Format that I am used to"	"You can turn, rotate, and flip to see all angles"	"Can visually and physically see what the finished product should look like rather than imagine and think (it)"
"Can refer back easily and am accustomed to use"		"Being able to process the 3D at once is preferred over the multiple 2D drawings for the same info"
"Presents info floor by floor instead of all at one time"		
"Everything was clearer and less stressful"		

The individuals that preferred the 2D drawing sets often responded it is due to the fact that they were easy to understand and what they were used to. In fact, there were 12 practitioners that preferred the 2D drawings and 6 responded that it was due to their familiarity with drawings. 3D computer model preferences were often due to the ability to rotate and visualize a full image as well as including relevant project information. The subjects that preferred the physical model had several interesting quotes as to their reasons. From the responses, the concept of a single, physical source for information is well received by the subjects.

5.3.2. Practitioner Preferences for Construction Task Scenarios

As previously mentioned, the post-test questionnaire presented the subjects with various real construction scenarios that require the use of spatial information and asked which information format should be referenced to complete the task. The scenarios presented were chosen to represent situations where there is a display format that is advantageous. In section 3.2.7 “Weaknesses of 2D Presentations of 3D Information in Human Factors”, the proven advantages and disadvantages of 2D versus 3D are discussed. Table 5.28 summarizes the desired information traits. Relative positioning presents better in two dimensions, as the specific planar dimensions can be focused on, and the third, and unnecessary dimension, is eliminated. When projective ambiguity is a concern, a two dimensional format is superior. Projective ambiguity exists when three dimensions are recreated in a two dimensional format, resulting in a distorted third dimension. 3D displays better represent shape understanding as a full 360º viewing angle can be achieved. In a similar fashion, a 3D display allows the user to focus on a plane while still having quick reference to a third dimension. When understanding a layout or terrain, a profile view can be accessed while also having the depth (or width, depending on the chosen profile) dimension readily available. Finally, a 3D display allows for depth cues to be referenced. This means that a 2D sheet can be studied while also having the third (depth) dimension represented to give a point of reference for depth and location.

Table 5.28 2D versus 3D Display Comparisons

Tasks where 2D Displays are advantageous	Tasks where 3D displays are advantageous
Relative Positioning	Shape Understanding
Projective Ambiguity Concern	Layout Understanding
	Depth Cues

There were four tasks presented in the post-test questionnaire to identify preferences of the practitioners. The tasks were:

- You are a structural steel subcontractor and need to plan and present an erection sequence, which information delivery format(s) would you use to complete the task (2D, 3D Interface, Physical Model)?
- If you are calculating the necessary cubic yards of concrete for an upcoming slab pour, which information delivery format(s) would you use to complete the task (2D, 3D Interface, Physical Model)?
- If you are a mechanical, electrical, or plumbing (MEP) engineer and need to design piping runs with sufficient access space, which information delivery format(s) would you use to complete the task (2D, 3D Interface, Physical Model)?
- If you are estimating the quantity of earthwork that will have to be cut and/or filled on a project, which information delivery format(s) would you use to complete the task (2D, 3D Interface, Physical Model)?

In a construction setting, a structural steel erection plan requires an understanding of relative positioning, as it involves coordination of the construction of steel shapes in two directions or dimensions. Therefore an ideal information format choice would be the 2D drawings. Calculating the required yardage of concrete for a future placement event requires an understanding of the shape and the ability to measure distances. Shape understanding presents well in three dimensions, which would point towards the 3D computer model or the physical model. Being that distances are represented and automatically calculated in the computer software, the 3D computer model provides the best representation. MEP runs are typically associated with having sufficient access and coordination between the trades to fit the pipes in the allowable space provided. This requires depth cues and shape understanding without projective ambiguity. The depth cues and shape understand lends itself towards a 3D model, while projective ambiguity concerns lead the user towards a 2D representation. However, a physical model provides the necessary depth cues and shape understanding in a proper and efficient 3D representation. Finally, estimating the quantity of earthwork for cut and fill requires project information and layout understanding of the terrain. Similar to the concrete placement scenario, a 3D computer has the necessary display, information, and calculating tools to complete the task.

Having reviewed the scenarios and proper information format displays, Figures 5.22, 5.23, 5.24, and 5.25 display the preferences for practitioners to complete the steel erection plan, concrete placement, MEP coordination, and earthwork quantity calculation tasks respectively.

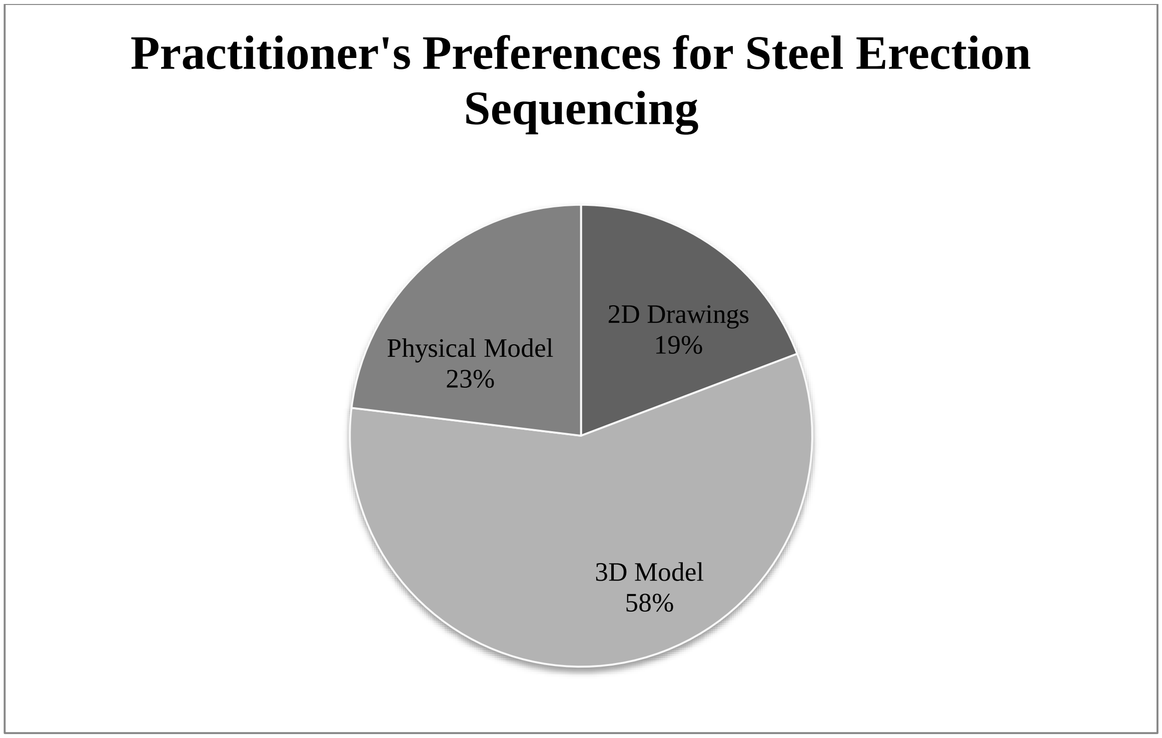


Figure 5.22 Practitioner's Preferences for Planning Steel Erection Sequence

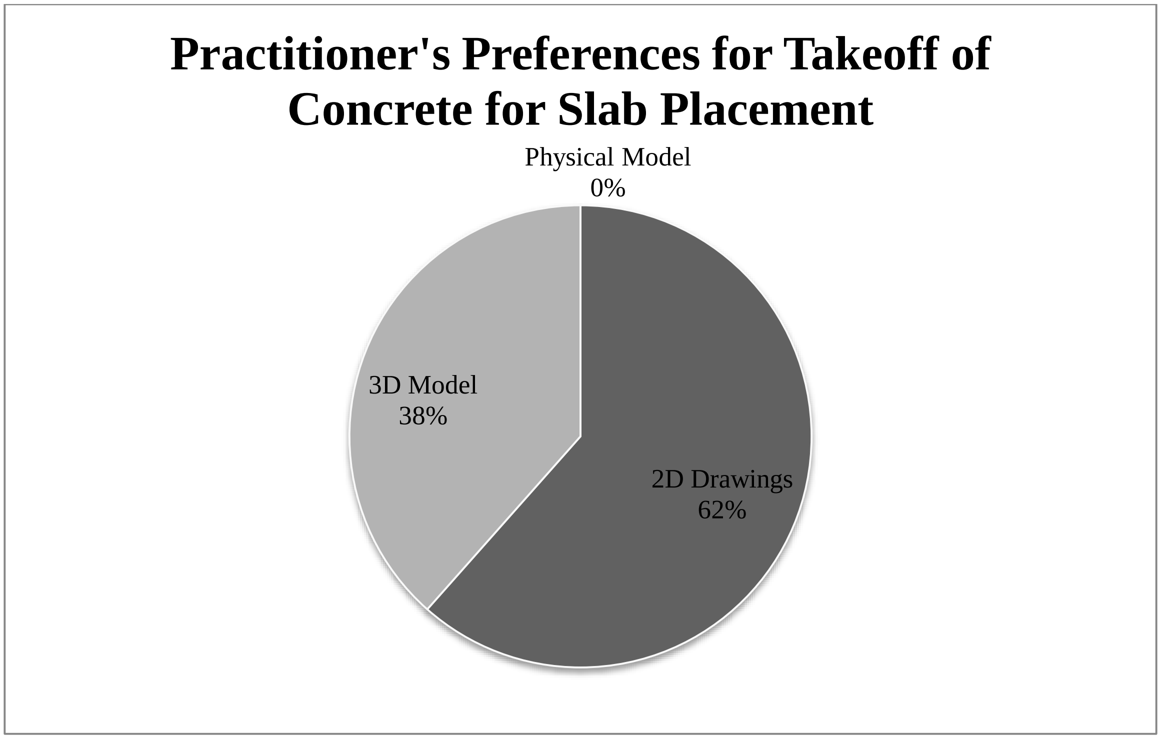


Figure 5.23 Practitioner's Preferences for Quantity Takeoff of Concrete for Slab Placement

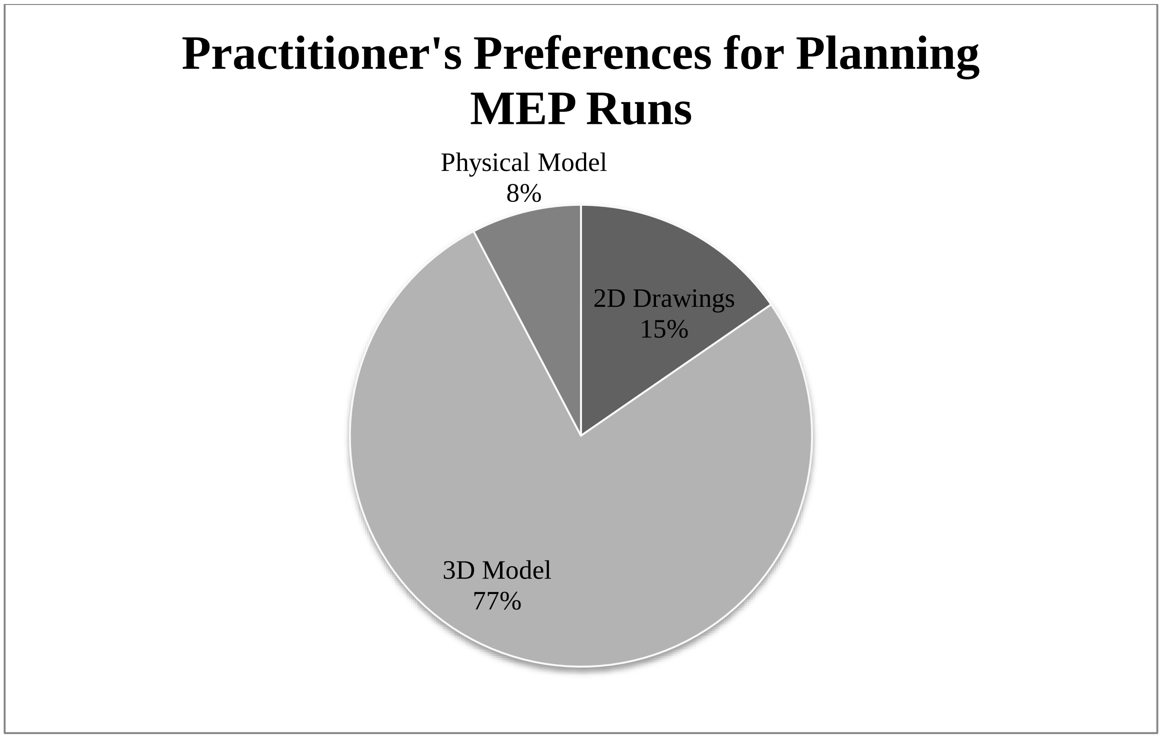


Figure 5.24 Practitioner's Preferences for Planning MEP Piping Runs

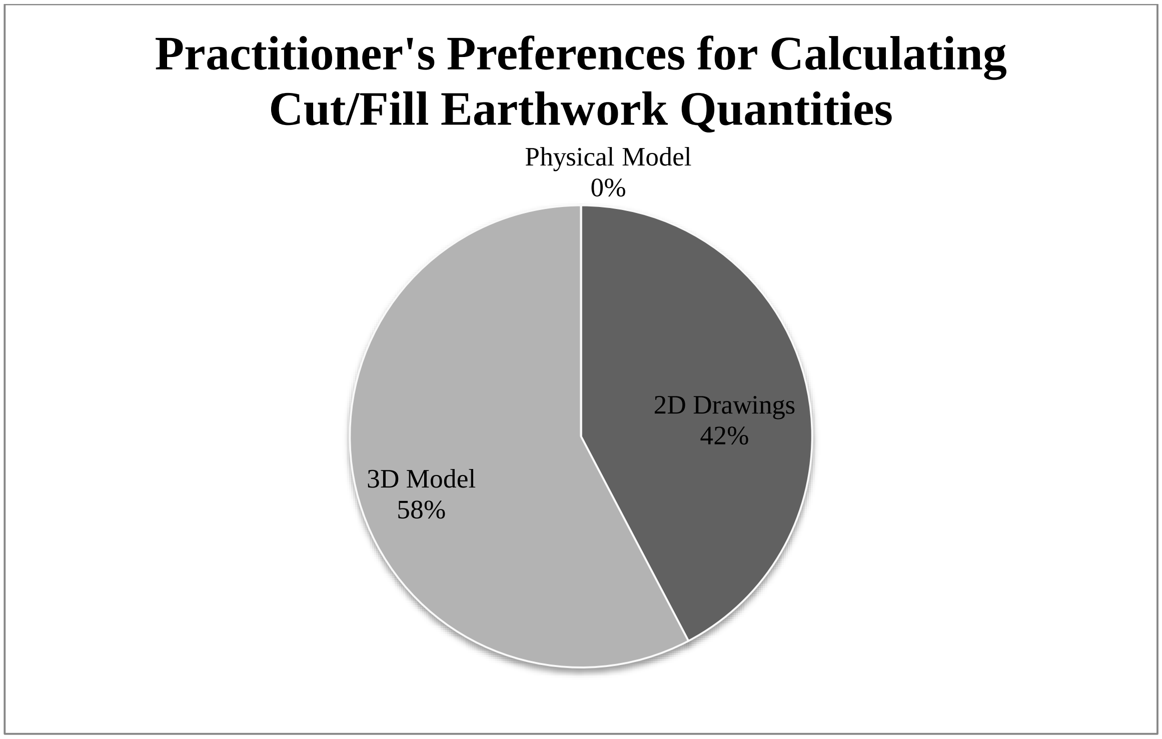


Figure 5.25 Practitioner's Preferences for Calculating Cut and Fill Earthwork Quantities

For the steel erection sequence plan, subjects preferred the 3D computer model 58% of the time, 2D drawings 23%, and a physical model 19%. Literature suggests the 2D drawings would be preferred as it gives a proper viewing of relative positioning of the steel members. A 3D computer model would distort distances due to projective ambiguity and does not provide addition information that would be desirable. In addition, the practitioners did not perform a simple steel erection sequence during the task completion. It would be a reasonable assumption that a more complex project with more moving parts would prove even more difficult.

When calculating concrete quantities for a slab placement, 62% of practitioners preferred using 2D drawings compared 38% preferring a 3D computer model and 0% for a physical model. This task requires shape understanding and understanding of necessary dimensional properties, which makes a 3D computer model a superior choice. Given this information, subjects likely prefer the 2D drawings due to their limited experiences with CAD technologies. In the current CAD software packages, a concrete slab element can be clicked on and exact quantities will immediately be presented. Without this knowledge and experience, practitioners revert to their familiarity with quantity takeoffs from two dimensional drawings.

With the need for depth cues, shape understanding, and avoidance of projective ambiguity, coordinating the locations of mechanical, electrical, and plumbing pipes is a demanding task. On one hand, depth cues and shape understanding require a 3D display, while a standard 3D display presents issues of projective ambiguity. The issue is averted in a physical model where subjects benefit from depth cues and shape understanding of a 3D display and avoiding projective ambiguity from a true three dimensional, haptic output. However, an overwhelming 77% of practitioners preferred a 3D computer model, while 15% and 8% chose 2D drawings and a physical model respectively.

Calculating cut and fill earthwork quantities requires a knowledge of the terrain and layout, and ideally, the ability to quickly calculate volumes. 3D CAD software packages are readily equipped with this capability and provide a 3D display that is optimal to complete the task. 58% of practitioners appropriately identify the 3D computer model as the information format of choice for this operation, while 42% would use the standard 2D drawing set and 0% would reference a physical model.

When these responses are aggregated (see Figure 5.26), 58% of practitioners would use a 3D model for the construction tasks. 34% and 8% would use 2D drawings and a physical model respectively. These numbers are interesting, as Sections 5.2.4 and 5.2.8 showed that practitioners perform better with a physical and Section 5.3.1 found that 2D drawings are the preferred format. Practitioners had difficulty manipulating the computer model to a proper and efficient orientation. In fact, several practitioners could not turn the computer model towards a desired display and ended up turning their work platform to match the orientation on the screen. With this much difficulty with a simple structural model, a more complex and layered computer model, as are the ones currently populating the industry, would prove to be too burdensome and laborious for efficient field interpretation.

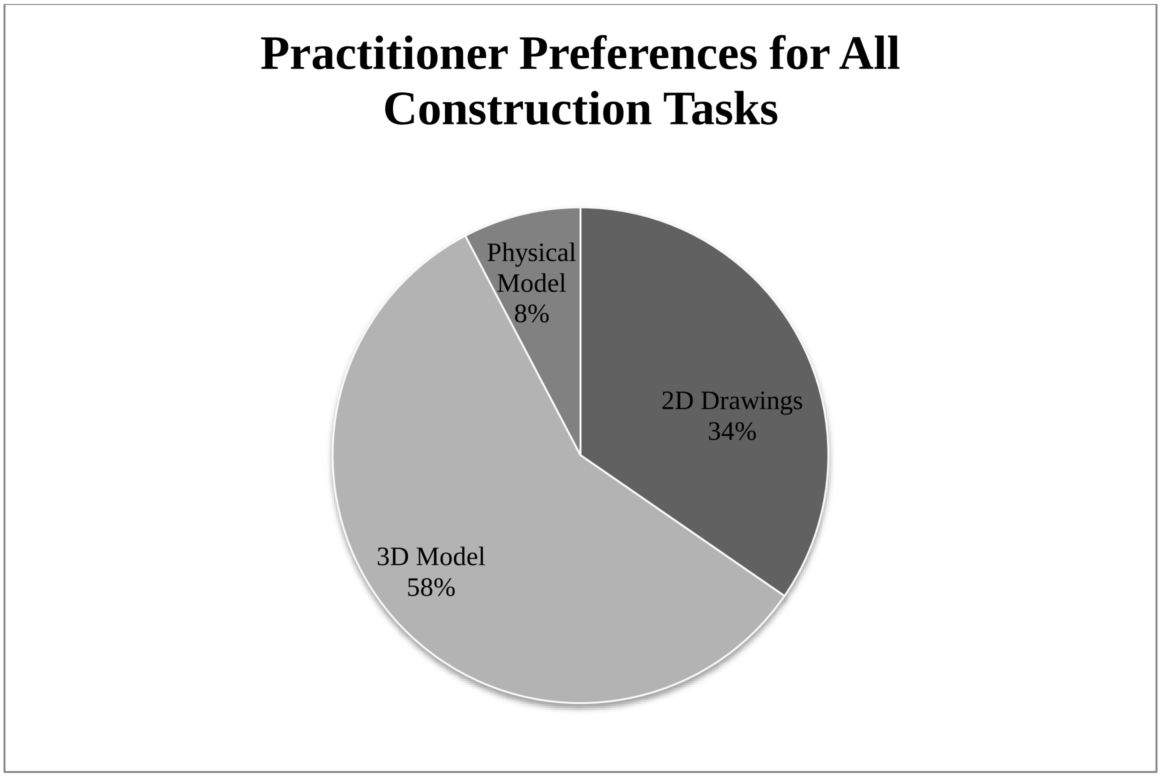
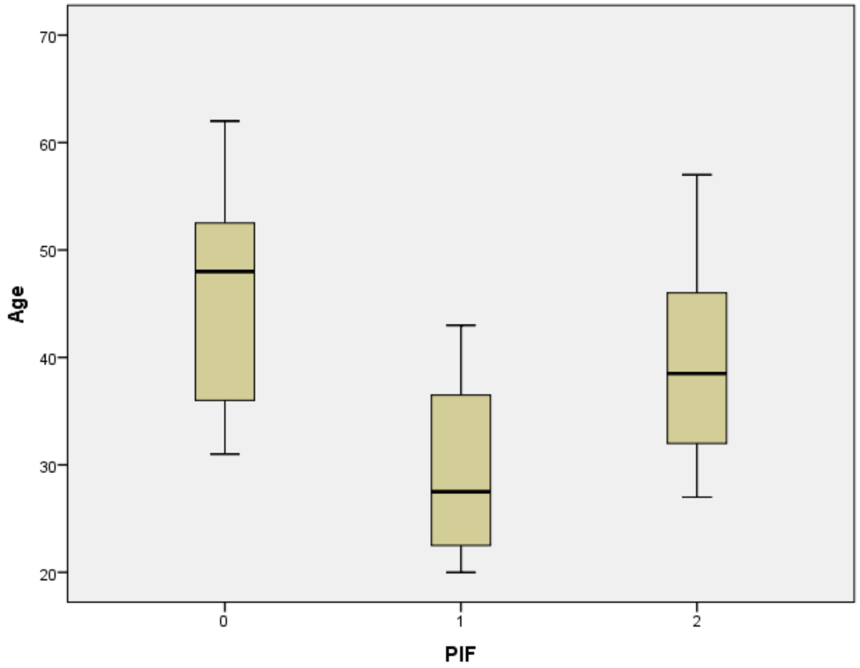


Figure 5.26 Practitioners' Preferences for All Construction Tasks

5.3.3. Practitioner Preferences Based on Demographic Factors

The post-test questionnaire asked subjects to respond to several questions with regards to their preferred model type. One was focused strictly on their overall preference, and four other questions posed several construction tasks that require spatial information. The results from this portion of the questionnaire are presented in Section 5.3.2. Overlaying practitioner preferences with demographic data such as age, years of experience, and CAD expertise could yield an understanding of why individuals responded a certain way.

First, using age as the key demographic, the box plots for the preferred information format, the steel erection sequence, calculating concrete quantities, coordinating piping runs, and calculating earthwork quantities questions are found in Figures 5.27, 5.28, 5.29, 5.30, and 5.31. The trend on age appears that younger practitioners prefer the computer model to use for many of the tasks, while the 2D drawings are the most popular selection for the older practitioners.



0 - 2D Drawings, 1 - 3D Computer Model, 2 - Physical Model

Figure 5.27. Box-plot diagram, age vs. preferred information format, practitioners only

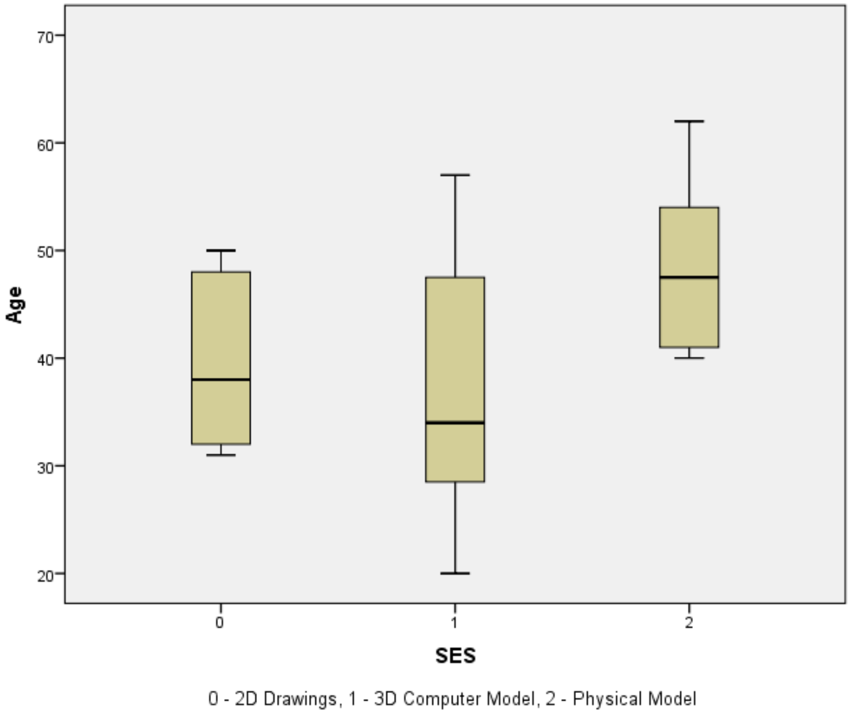


Figure 5.28 Box-plot diagram, age vs. steel erection sequence preferred model, practitioners only

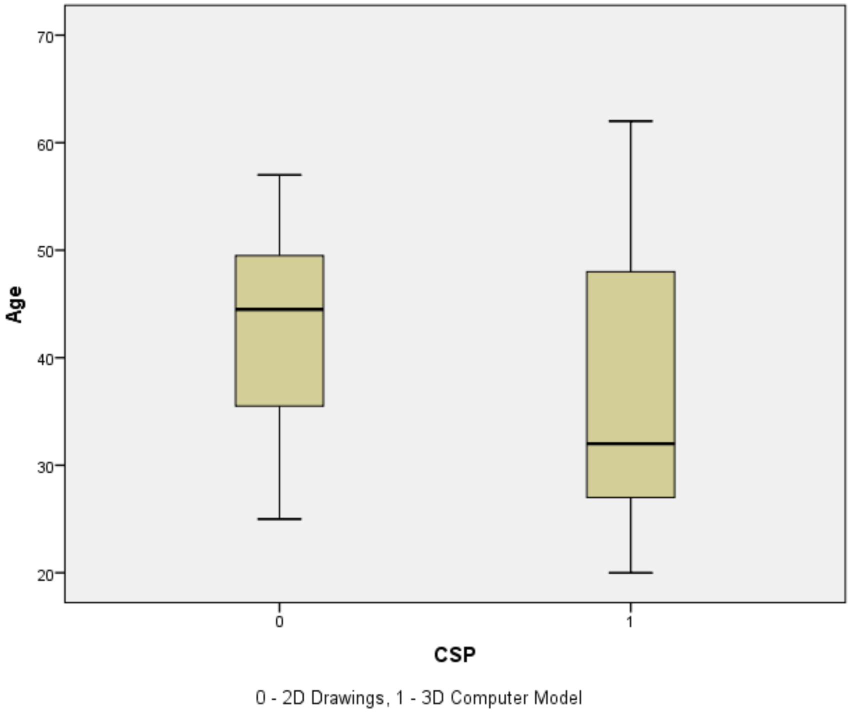


Figure 5.29. Box-plot diagram, age vs. calculating concrete quantity preferred model, practitioners only

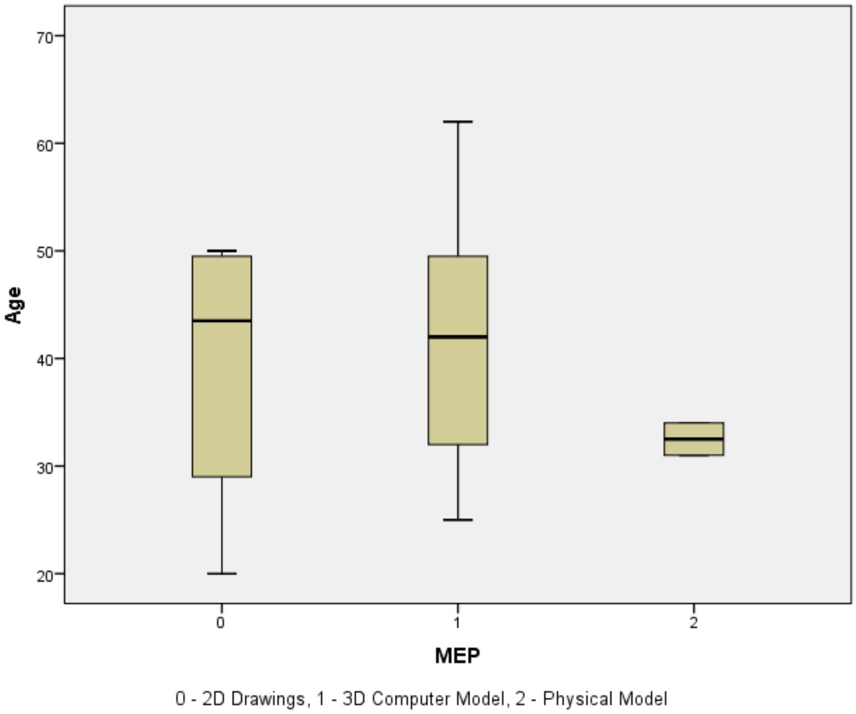


Figure 5.30 Box-plot diagram, age vs. piping coordination preferred model, practitioners only

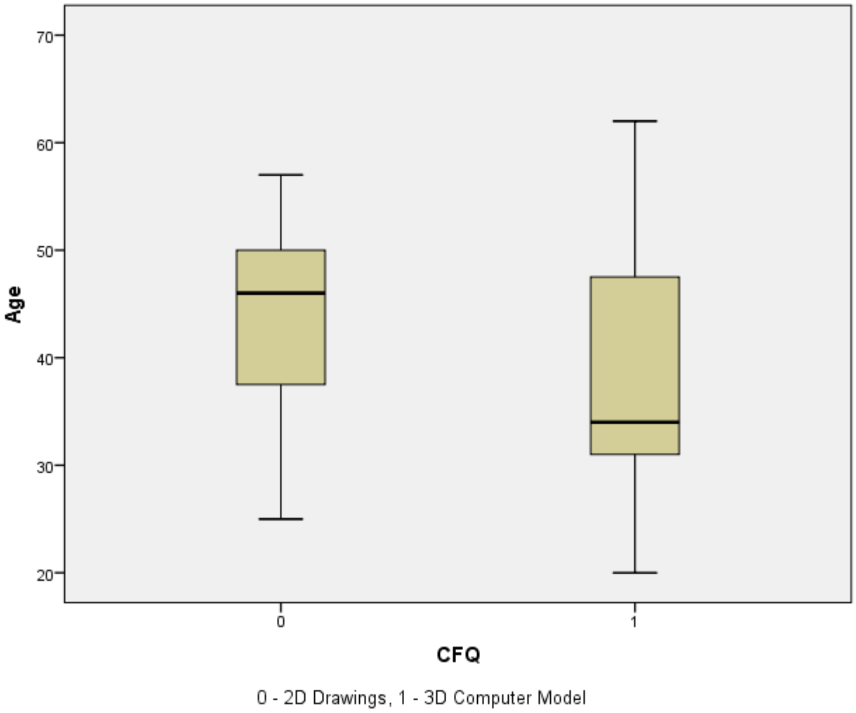


Figure 5.31. Box-plot diagram, age vs. calculating earthwork quantities preferred model, practitioners only

Another key demographic note is the years of experience for the practitioners. Figures 5.32, 5.33, 5.34, 5.35, and 5.36 show the box-plot diagrams for the post-test questions against the amount of experience. There are some interesting results in comparison to the responses based on age.

Similar to age, the preferred information format for lesser experienced practitioners is the 3D computer model with 2D drawings being the preferred choice for practitioners with more experience. The practitioners also responded similarly to the questions about calculating the amount of concrete required for a slab placement and calculating earthwork quantities where a 3D model was most preferred by those with less experience.

However, the questions posed concerning a steel erection sequence and coordination of piping installation had different results when compared to age and experience. Individuals with less experience preferred the 2D drawings the least for a steel erection sequence and a physical model for coordination of a piping run. Those with the most experience preferred the physical model and 3D computer model for the steel erection sequence and coordination of pipes respectively.

Interestingly, the older workers did not perform nor prefer the 3D computer model, however, that did not always translate to those with the most experience. This could mean that age has a stronger impact on the indifference towards the computer model and that added experience, and likely training, can overcome that barrier.

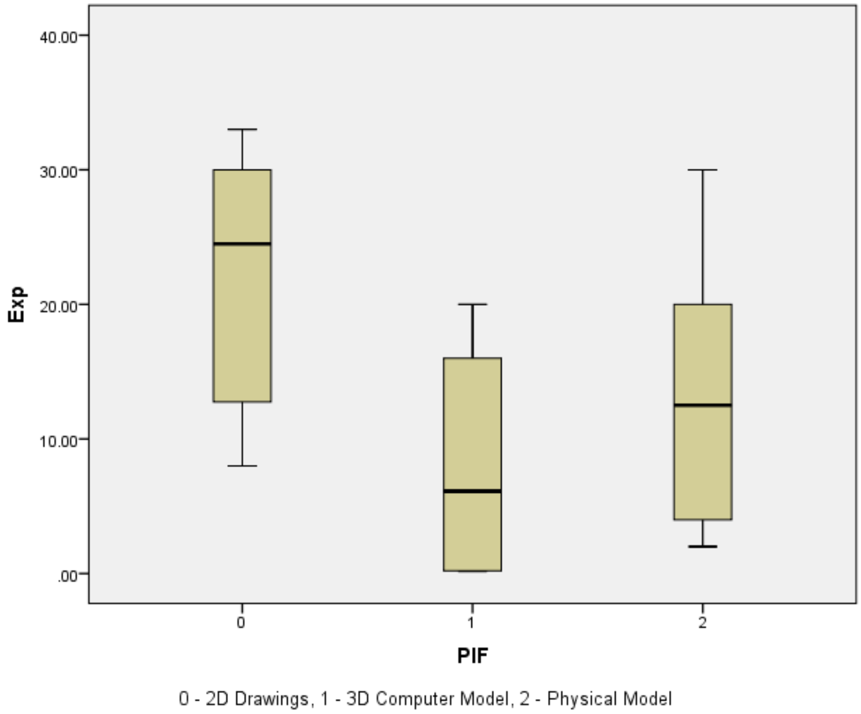


Figure 5.32. Box-plot diagram, experience vs. preferred information format, practitioners only

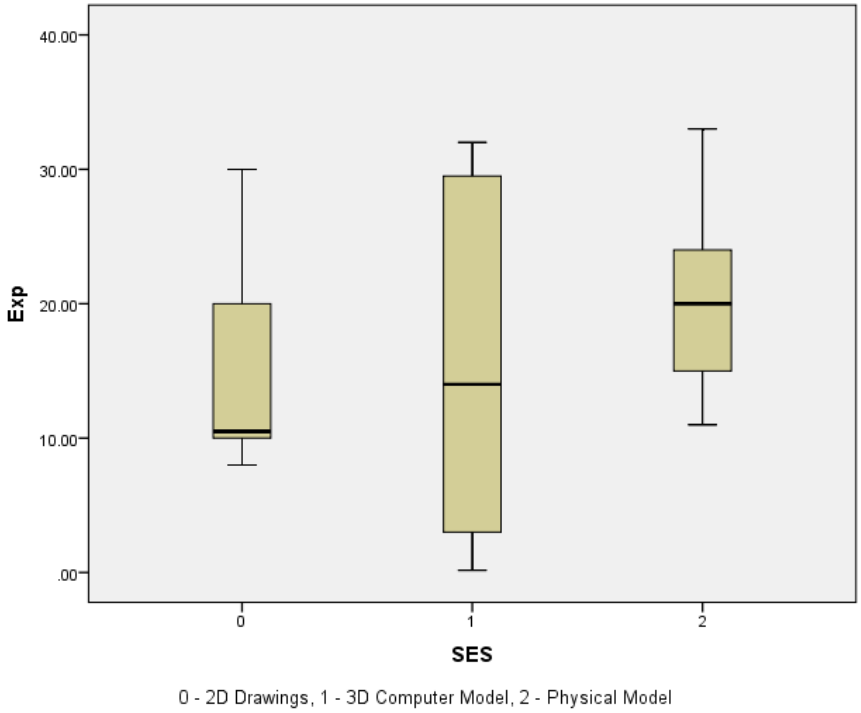


Figure 5.33. Box-plot diagram, experience vs. steel erection sequence preferred model, practitioners only

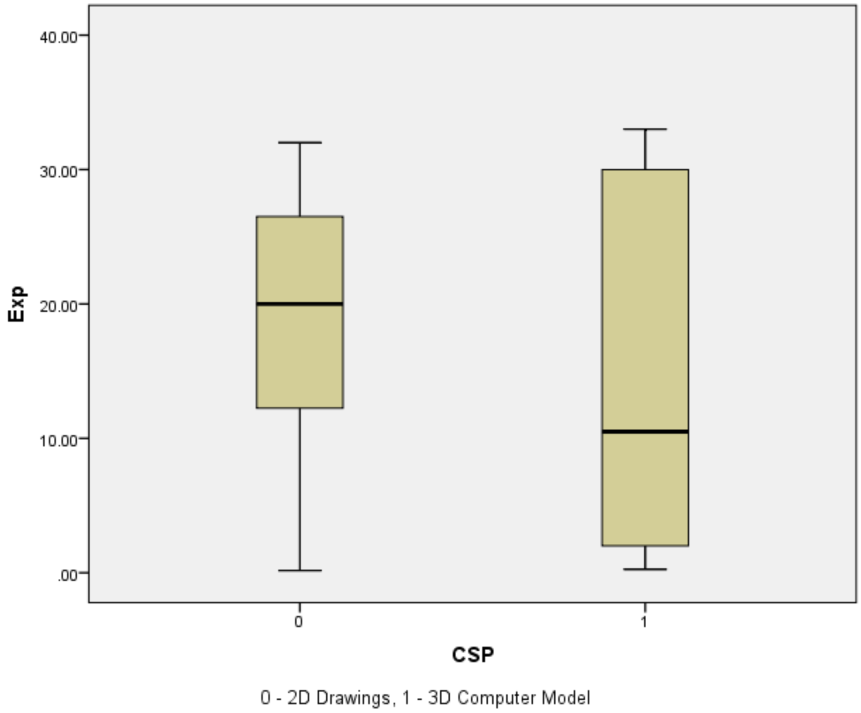


Figure 5.34. Box-plot diagram, experience vs. calculating concrete quantity preferred model, practitioners only

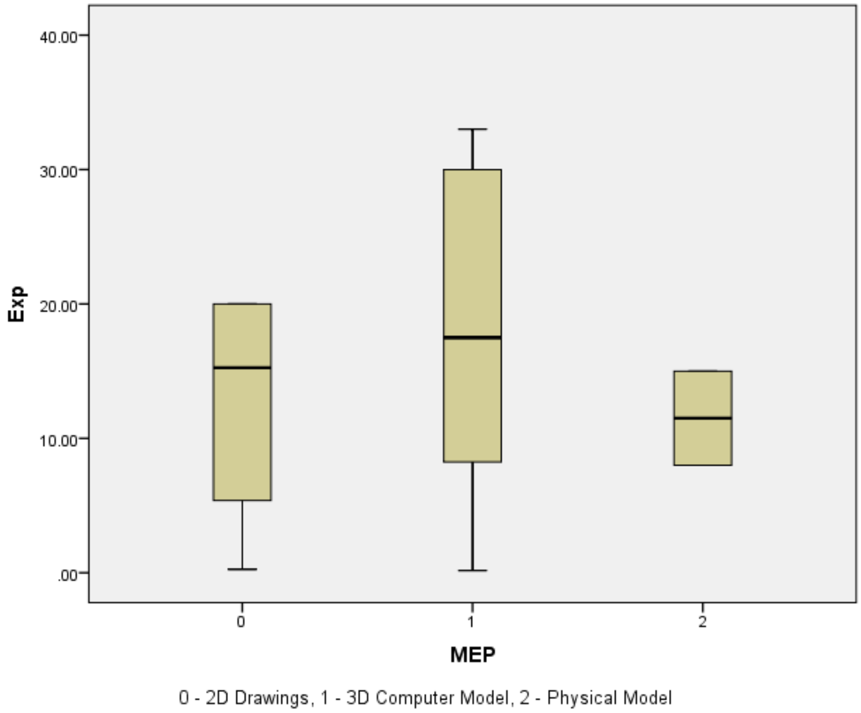


Figure 5.35. Box-plot diagram, experience vs. piping coordination preferred model, practitioners only

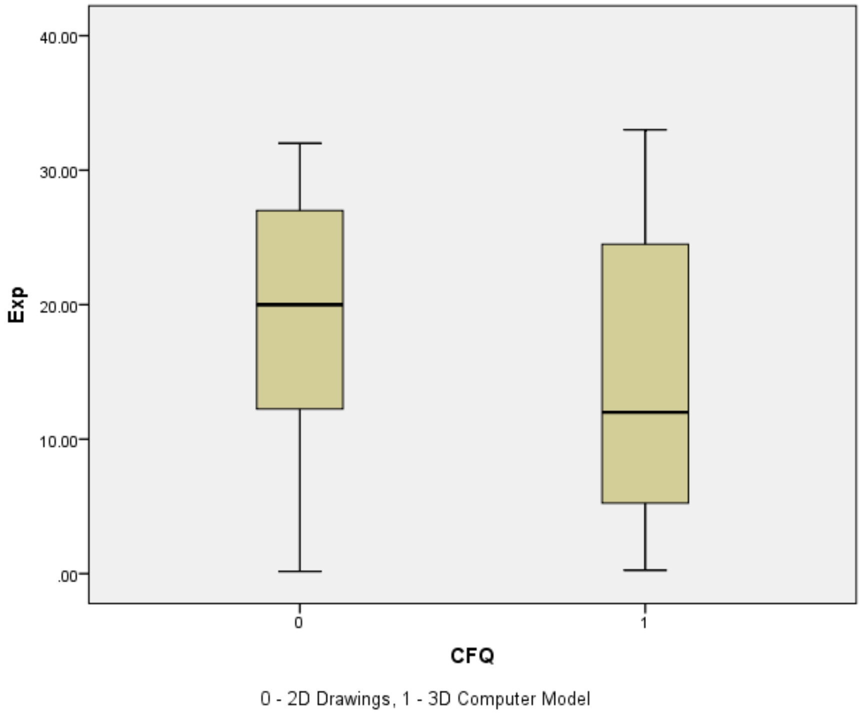


Figure 5.36. Box-plot diagram, experience vs. calculating earthwork quantities preferred model, practitioners only

5.3.4. Cognitive Performance of Practitioners

While Sections 5.2.3 and 5.2.4 found no statistically significant difference among the model types and the resulting cognitive performance of the subjects, there are worthwhile takeaways involving cognitive measures. Focusing on the outcomes from the NASA-rTLX questionnaire, Figure 5.37 and Table 5.29 illustrates the ratings by model type for the overall composite workload score, mental demand, physical demand, temporal demand, operator performance, effort and frustration. Lower values are preferred for all response factors.

Overall, the physical model requires the least amount of mental workload, 4.0% less than two-dimensional drawings and 13.0% less than the two-dimensional computer model. The mental demand of practitioners is also lower in the physical model than the 2D drawings and 3D computer model by a factor of 8.9% and 21.7% respectively. This pattern continues for all of NASA-rTLX factors except for the levels of effort and frustration where the 2D drawings outperformed the 3D computer model and physical model. This outcome is well aligned with the performance given from the previous statistical analyses and the preferences discussed in the previous section. Practitioners responded that the physical model requires the least amount of mental, physical, and temporal demand while feeling that self-performance was highest for the physical model. However, levels of effort and frustration indicated that the 2D drawings would be preferred likely due to familiarity through daily exposure.

Table 5.29 NASA-rTLX response means for practitioners

Model Type	Composite	Mental Demand	Physical Demand	Temporal Demand	Performance	Effort	Frustration
2D	33.72	39.42	30.96	45.38	22.12	40.77	23.65
3D	36.63	44.04	30.58	44.23	26.73	44.42	29.81
Physical	32.41	36.20	27.60	43.20	21.80	42.20	26.20

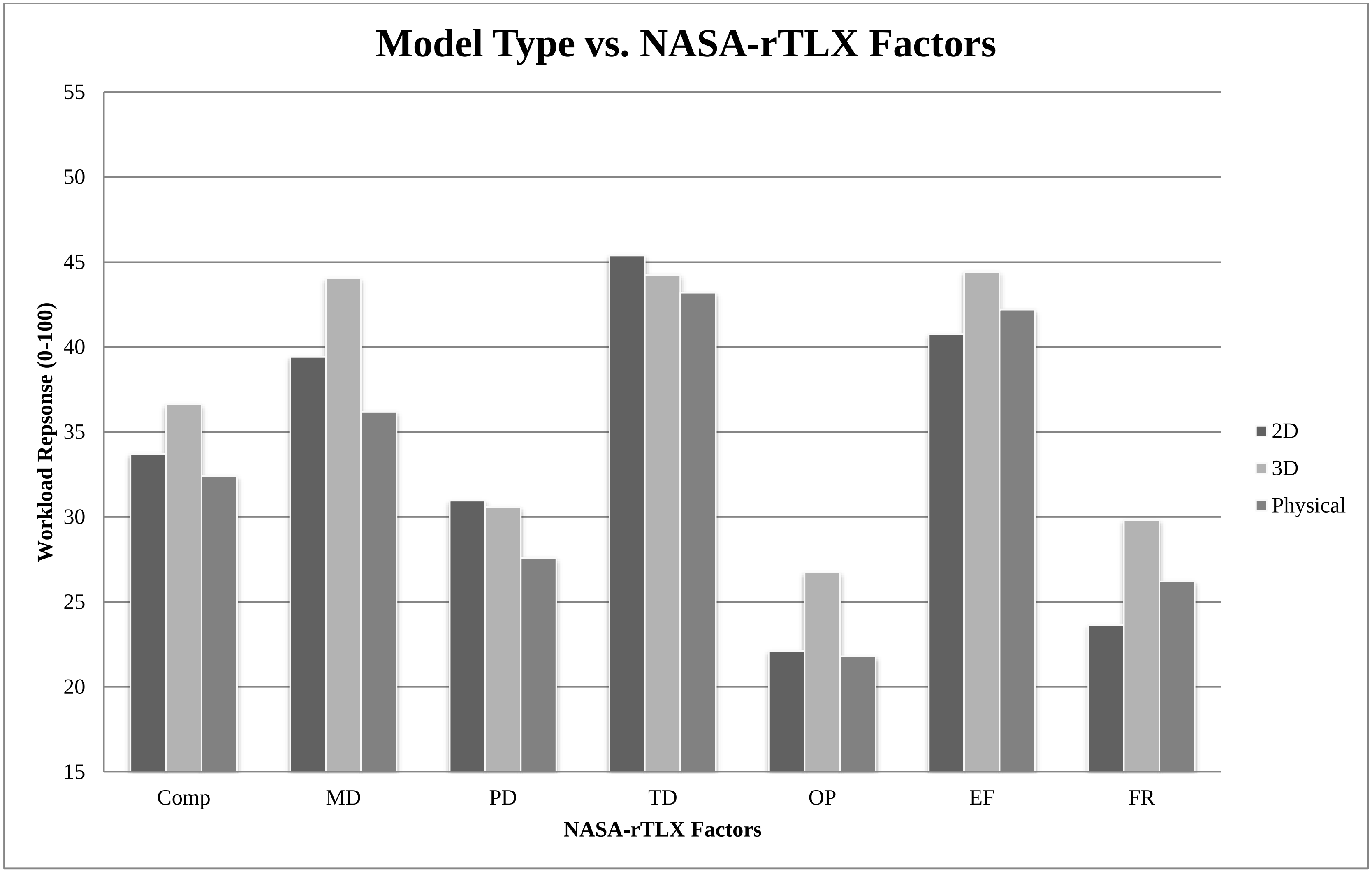


Figure 5.37 NASA-rTLX factors by model type, practitioners only

5.4. Analysis of Student Preferences and Performance

5.4.1. Student Preferences for Task Completion

The student sample group was smaller than the practitioner sample, however, there are significant differences in their preference responses. When asked what model format is preferred to complete the task experiment, 46% of students preferred the physical model compared to 27% each for 2D drawings and a 3D computer model (see Figure 5.38). Since the objective performance results show that students performed better with a physical model, this would appear to be a logical response rate.

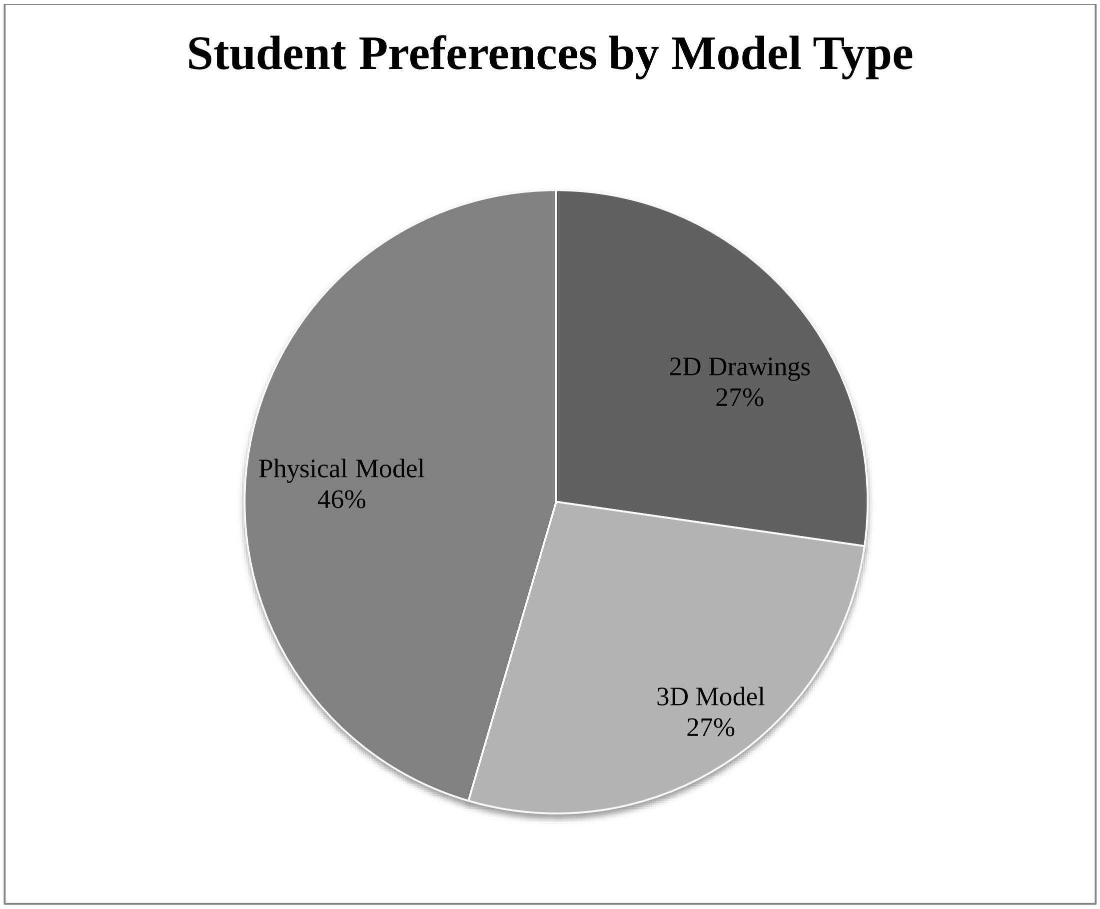


Figure 5.38 Students' preferences for task completion by model type

The students were also asked to describe reasoning behind their choice for preferred model for the task (see Table 5.30). Many of the responses were similar to that of the practitioners, with a few differences. Some of the students preferred the 2D drawings for the ability to sequentially see information rather than present it all at one time. The individuals that preferred the 3D model because it represents the full structure, however, they did not differentiate that reasoning from a physical model that displays the same properties. Those that preferred the physical model favors the haptic and mobility aspects of a physical model, which translates well for the experiment.

Table 5.30 Selected responses to model preferences, students only

Responses from students that preferred 2D drawings	Responses from students that preferred a 3D computer model	Responses from students that preferred a physical model
"Easy to understand"	"Provides various aspects of the building to capture comprehensive picture"	"Likes haptic nature"
"Easier to just see one floor at a time"		"I can touch it and bring it close to my face"

5.4.2. Student Preferences for Construction Task Scenarios

The post-test questionnaire given to both practitioners and students presented a series of actual field tasks that would require the reference of engineering information, typically a set of two dimensional drawings. The subjects are then asked to respond with what format would one reference to complete the task. There were four tasks presented in the post-test questionnaire to identify preferences of the students. The tasks were:

- You are a structural steel subcontractor and need to plan and present an erection sequence, which information delivery format(s) would you use to complete the task (2D, 3D Interface, Physical Model)?

- If you are calculating the necessary cubic yards of concrete for an upcoming slab pour, which information delivery format(s) would you use to complete the task (2D, 3D Interface, Physical Model)?
- If you are a mechanical, electrical, or plumbing (MEP) engineer and need to design piping runs with sufficient access space, which information delivery format(s) would you use to complete the task (2D, 3D Interface, Physical Model)?
- If you are estimating the quantity of earthwork that will have to be cut and/or filled on a project, which information delivery format(s) would you use to complete the task (2D, 3D Interface, Physical Model)?

For a lengthier discussion on the selection of these tasks and what format is ideal for the tasks is outlined in Section 5.3.2. The student responses to the previous tasks can be seen in Figures 5.39, 5.40, 5.41, and 5.42, respectively.

A steel erection sequence could easily be planned on a set of 2D drawings due to its strength in relative positioning on a 2D planar space. However, 64% of students suggested that a 3D model would be used for this task. For calculating the quantity of concrete necessary for a placement, 55% of the students suggested that a 3D model would be the chosen format. Based on spatial literature, a 3D model, actually, would be the preferred format as it allows for shape understanding and a quick interpretation of spatial dimensions. 62% of practitioners chose the 2D drawings for this task. When planning MEP piping runs, 73% of students would choose a 3D model for this task. Literature suggests a 3D display would be a preferred option due to the need for shape understanding and depth cues. However, this task requires referencing all three dimensional simultaneously, and a computer model would introduce projective ambiguity, distorting a third dimension. A physical model alleviates this concern and would be a better chosen format for this task. Finally, 64% of students would use a 3D model to calculate cut and fill quantities of an earthwork operation. This task requires layout understanding and calculating and referencing dimensional properties of the layout. This speaks to a 3D model that can quickly provide the necessary spatial and dimensional information needed to complete the task.

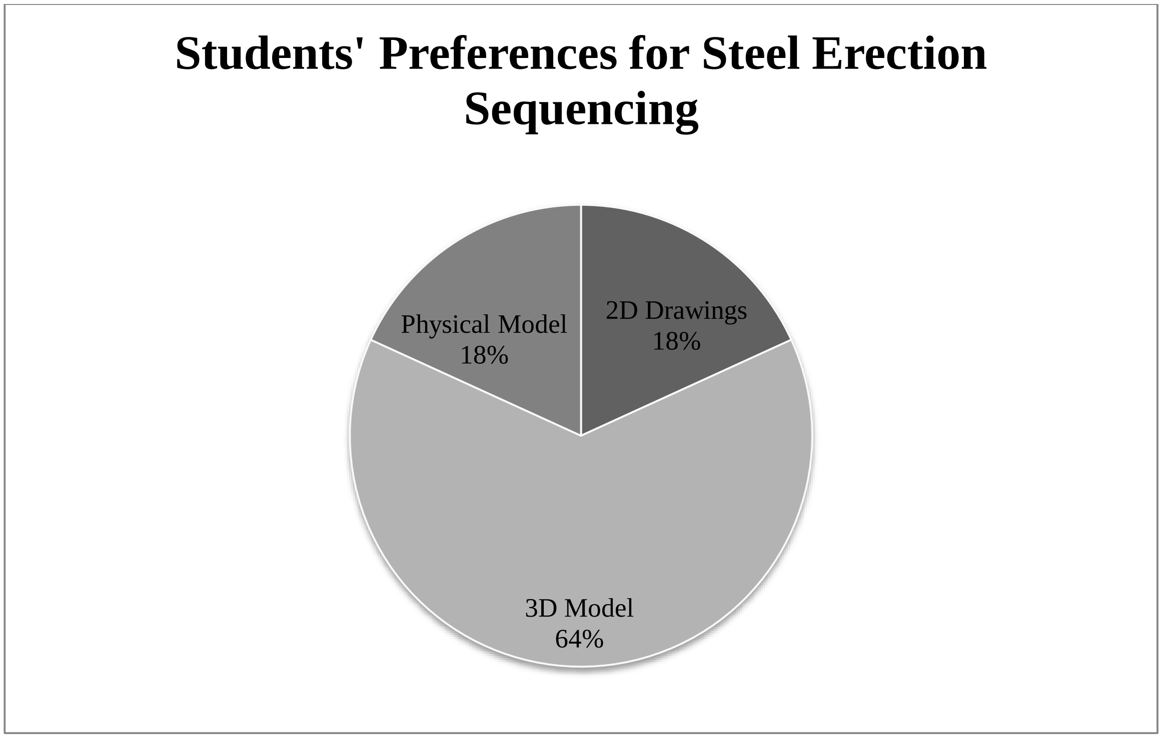


Figure 5.39 Students' model preferences for steel erection sequencing

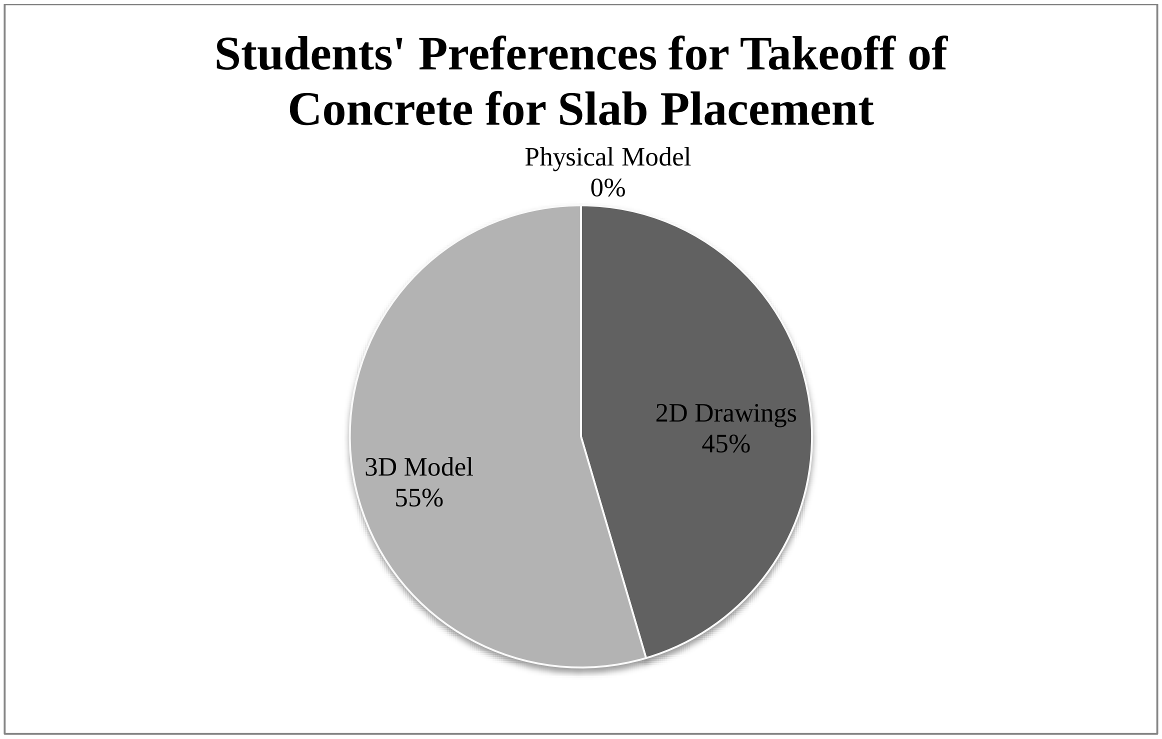


Figure 5.40 Students' model preferences for quantity takeoff of concrete for slab placement

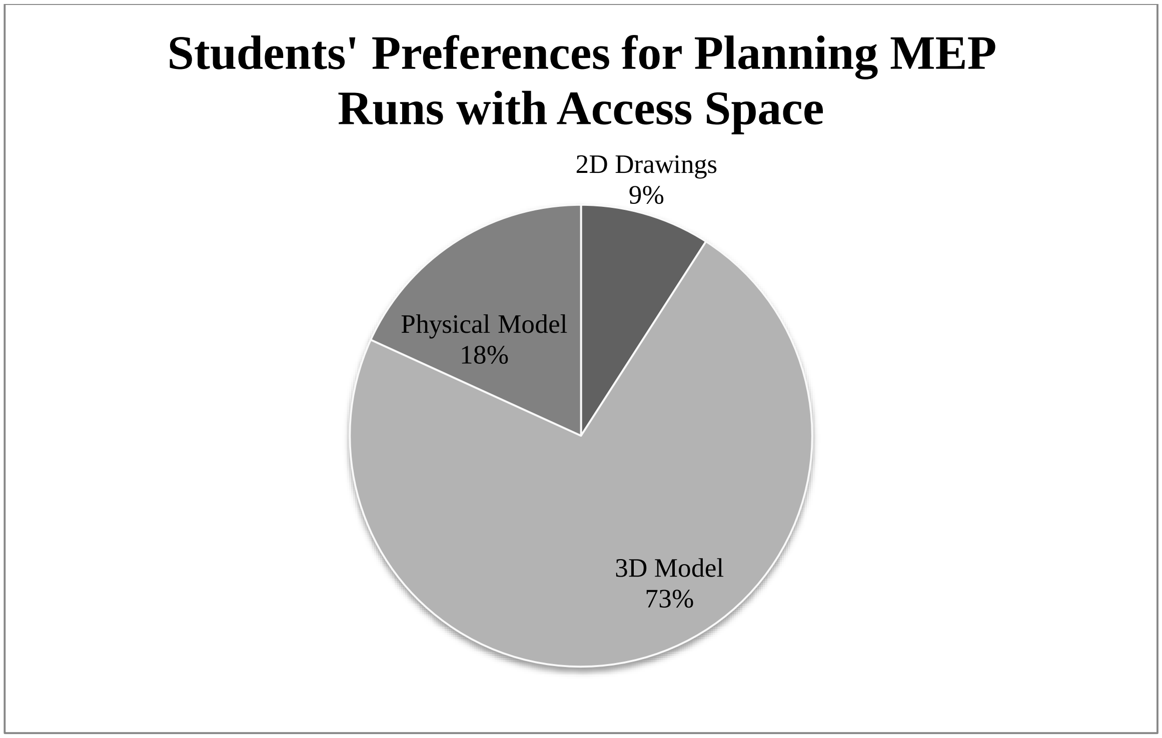


Figure 5.41 Students' model preferences for planning MEP piping runs

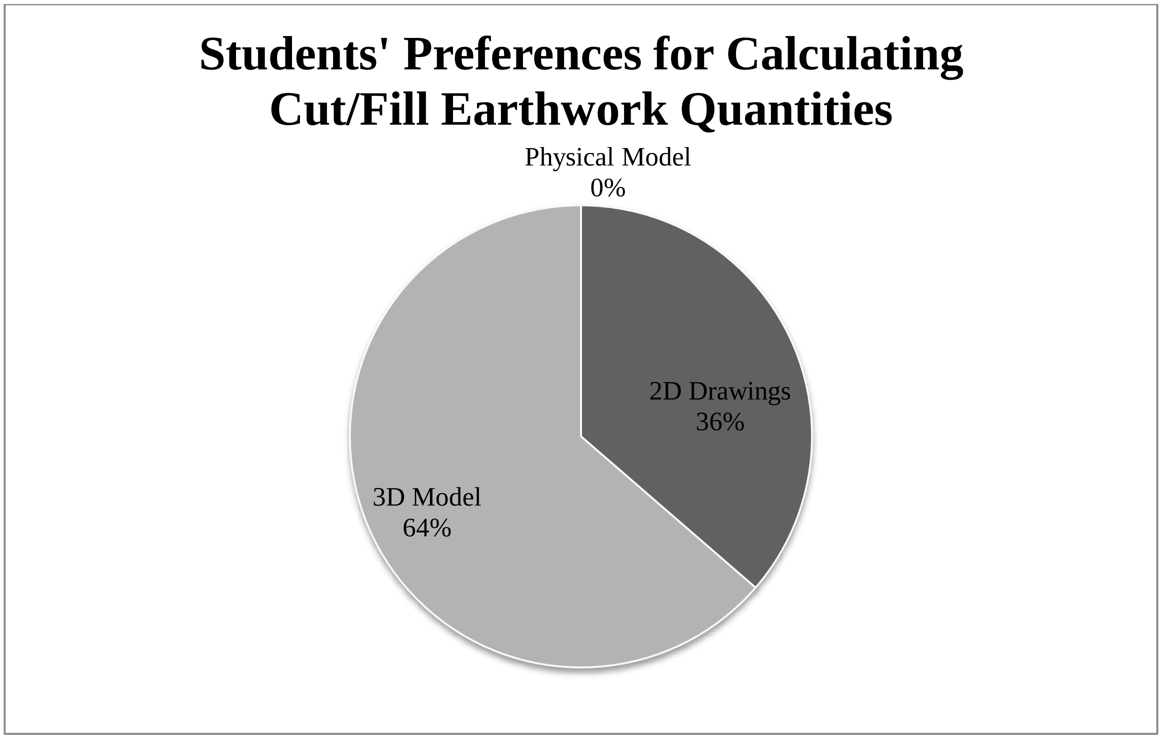


Figure 5.42 Students' model preferences for calculating cut and fill earthwork quantities

When responses for all construction tasks are combined, 64% of students would use a 3D model to complete real construction tasks (see Figure 5.43). Previously, it was found that students objectively perform the experiment better with a physical model and that a physical model would be their preferred model type to complete the experiment. This is a reasonable outcome, unlike the practitioners that performed better with a physical model, preferred 2D drawings for the test, and then would use a 3D computer model for construction scenarios.

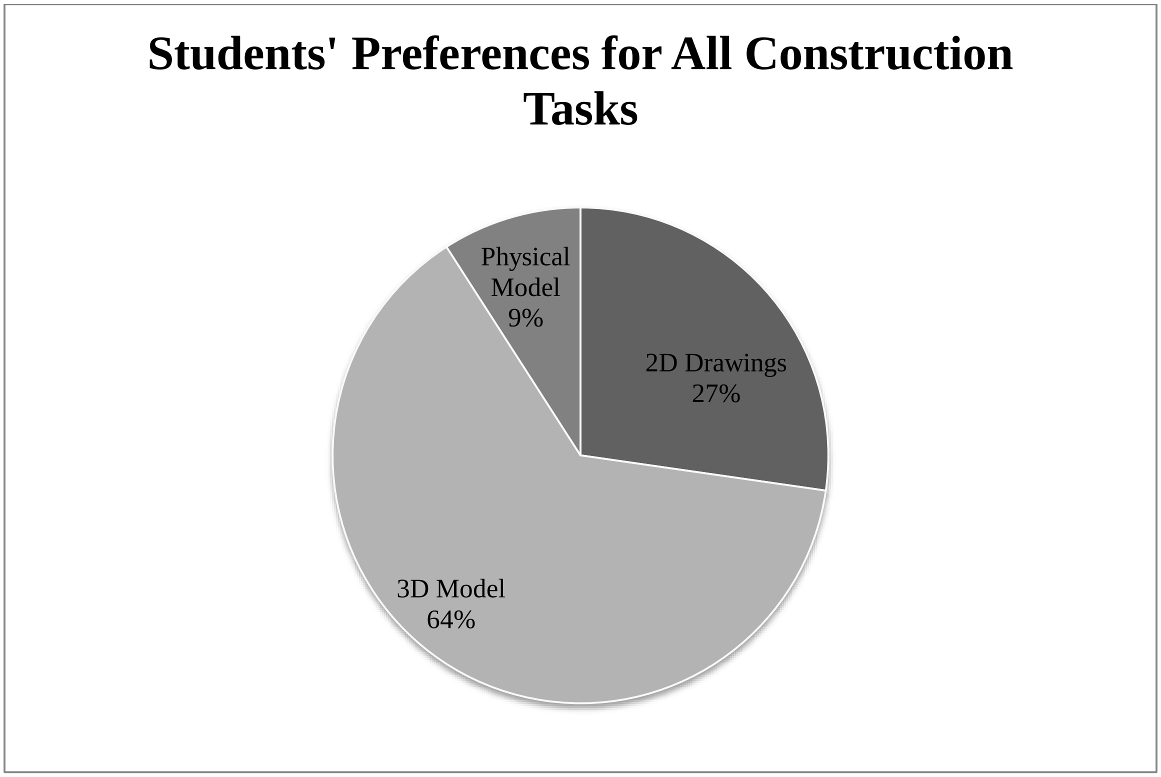


Figure 5.43 Students' model preferences for all construction tasks

5.4.3. Cognitive Performance of Students

In previous sections, student's outcomes were outlined from a statistical standpoint between all variables, as well as the student's preferences based on their experiences with the model types. This section takes a closer look at the cognitive outcomes from the

NASA-rTLX tool. Table 5.31 and Figure 5.44 provides the mean results by model types for the overall composite workload score and the six factors from the NASA-rTLX survey; mental demand, physical demand, temporal demand, performance, effort, and frustration.

Interestingly, students' order of cognitive demand of the model types is different than that of their practitioner counterparts. Overall, students found the physical model to be the least demanding followed by the 3D model and then the 2D drawings. The physical model outperformed the other model types in mental demand, temporal demand, performance, effort, frustration. The only factor where this trend was reversed was the physical demand, where the 2D drawings leveraged the least demand, then the 3D model, and finally the 2D drawings.

Table 5.31 NASA-rTLX response means for students

Model Type	Composite	Mental Demand	Physical Demand	Temporal Demand	Performance	Effort	Frustration
2D	32.88	37.73	23.64	51.36	19.09	37.73	27.73
3D	29.39	28.64	24.55	45.45	20.45	31.82	25.45
Physical	26.14	23.18	25.45	40.91	15.45	28.18	23.64

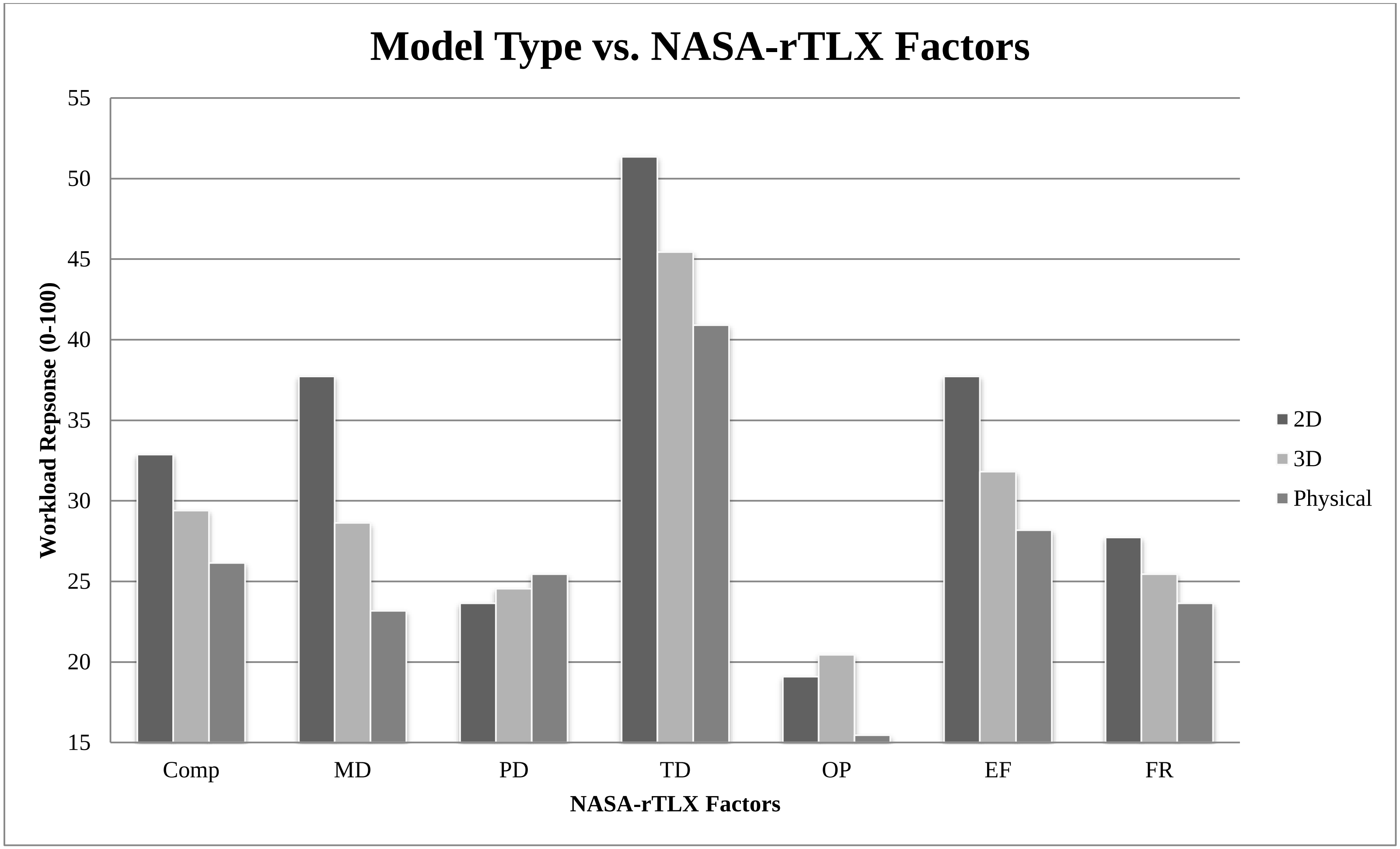


Figure 5.44 Mean NASA-rTLX factors by model type, students only

5.4.4. Comparison of Cognitive Performance of Practitioners and Students

The outcomes from the cognitive studies of practitioners and students reflect directly with their experiences and environment. Practitioners have lower cognitive demands when dealing with two dimensional drawings compared to a three dimensional computer model. This is their native information format in their daily work for however long their related work experience has been. Many of the tested practitioners had little to no experience with a computer three dimensional model. Often, this experience did not expand beyond viewing a screen shot of a 3D model or observing on-site management manipulate the model. Similarly, students have lower cognitive demands with a three dimensional computer model than a set of 2D drawings. Likewise, students have had courses in 3D computer modeling and are accustomed to working in a computer environment. The students do not have significant field experience in reading and interpreting construction drawings and, therefore, would be expected to be more challenged reading the drawings than the practitioners.

Figure 5.45 places the practitioner and student responses to the NASA-rTLX side by side for comparison, while Table 5.32 provides a numerical outline. As previously mentioned, the student responses with the 3D model are lower than that of the practitioners for all factors except for the time demand. This illustrates the relative difficulty that practitioners had when using the 3D computer model.

Table 5.32 NASA-rTLX response means for practitioners and students

Model Type	Composite		Mental Demand		Physical Demand		Temporal Demand		Performance		Effort		Frustration	
	Pract.	Students	Pract.	Students	Pract.	Students	Pract.	Students	Pract.	Students	Pract.	Students	Pract.	Students
2D	33.72	32.88	39.42	37.73	30.96	23.64	45.38	51.36	22.12	19.09	40.77	37.73	23.65	27.73
3D	36.63	29.39	44.04	28.64	30.58	24.55	44.23	45.45	26.73	20.45	44.42	31.82	29.81	25.45
Physical	32.41	26.14	36.20	23.18	27.60	25.45	43.20	40.91	21.80	15.45	42.20	28.18	26.20	23.64

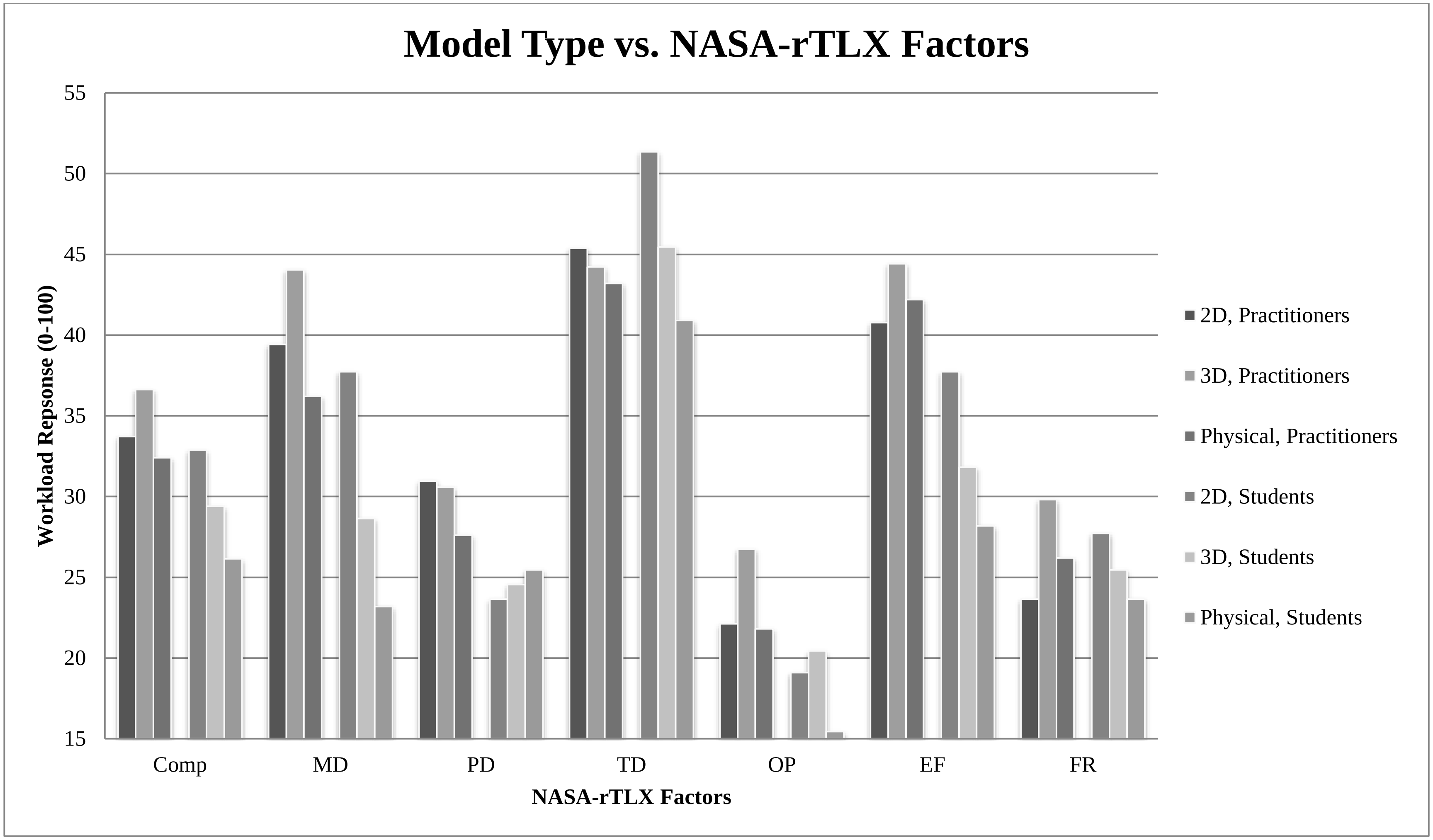


Figure 5.45 Mean NASA-rTLX factors by model type, practitioners and students

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

6.1. Findings

The research objectives, as mentioned in Section 1.2, for this study were to evaluate the effects that different mediums have on the human cognitive interpretation of spatial engineering information. In addition, secondary objectives were as follows:

1. Identify the uses of the different information mediums available for construction practitioners;
2. Identify the cognitive principles behind spatial information processing for engineering project information;
3. Develop a standard model for evaluating the cognitive interpretation of engineering information;
4. Develop and test assessment forms and a study for testing the effectiveness of the model; and
5. Identify the cognitive traits that are best served by different mediums.

The primary objective was met through the statistical analyses performed that determined a physical model presented spatial information in a faster, simpler, and easily interpretable manner. Objective number 1 was addressed through a literature review in current field practices discussed in Chapter 2. Secondary objective number 2 was met through an extensive review of cognitive psychology literature in Chapter 3. Section 4.1 presented a standard model that meets the requirements of the third secondary objective. The fourth secondary objective was satisfied in Sections 4.2 and 4.3 when outcomes were presented for the study. Finally, secondary objective number 5 was met throughout Chapter 5 and the rest of this chapter as significant findings are discussed.

From the previous results, there are several key conclusions that can be made:

1. In a measure of interpretation of spatial information by different formats, practitioners and students perform better with a physical model than two dimensional drawings and a three dimensional computer model. Physical models lead to less delays due to errors and preparatory time and more direct work time than 2D drawings and a 3D computer model.
2. There is a disconnect between task performance, preference, and scenario-based selection of various information formats. Practitioners cognitively perform better with a physical model, but prefer to complete the experiment with two dimensional drawings, however, envision the use of a three dimensional computer model for real tasks. Students also perform the task better with a physical model, however, they recognize their performance and preferred the physical model to complete the experiment. However, the students also suggested that they would use the 3D computer model for the scenario-based tasks.
3. Practitioners, without extensive training, have an inherent struggle navigating a simple 3D computer model. With lower spatial outcomes in the task performance, cognitive aspects, observations, and feedback than the 2D drawings and physical model, 3D computer model use would require training in a virtual environment to achieve a comfort level with practitioners, especially when the model becomes more complex. Similarly, students do not interpret spatial information from 2D drawings as well as their practitioner counterparts. While students do not leverage information 2D drawings as frequently as practitioners, there is an opportunity to improve their abilities through education and experience, in and out of a classroom.

From these conclusions, there are some immediate takeaways and recommendations for application in the construction industry when it comes to field delivery of spatial information. An extensive literature review in cognitive psychology and instructional design combined with the results from this dissertation allows for several recommendations that are summarized in Table 6.1.

Table 6.1 Recommended displays for construction tasks

Use 2D drawings for tasks involving…	Use a 3D computer model for tasks involving…	Use a physical model for tasks involving…
Layouts	Dimensional properties	Visualization of spatial elements
Limited, focused information	Repetitive calculations	Coordination of space
Relative object location	Shape properties	Depth understanding

The above recommendations are not intended to be a sole source reference for construction tasks. There are obviously numerous tasks that leverage information that are not outlined in the table. In addition, it is likely that many construction tasks might leverage a few of these spatial traits and would, therefore, demand that a combination of information formats might present an improved strategy.

A more detailed explanation of the key conclusions follows.

6.1.1. Practitioners and Students Performance With Different Mediums

When completing a simple task with different mediums, practitioners and students interpret spatial information best with a physical model, then two dimensional drawings, and finally a three dimensional computer model. There is a significant difference in the direct work rate, indirect work rate, and delays due to errors in performance of practitioners with different mediums.

Practitioners and students using a physical model work 13.10% more efficiently than with a set of 2D drawings and 20.44% more efficiently than with a 3D computer model. This can have large ramifications on a construction project if users are able to spend 20% more time on value adding work rather than interpreting information. Focusing on practitioners only, the values unveil more information. There is a 12.2% improvement on direct work rate with a physical model instead of 2D drawings and a 21.1% improvement over a 3D computer model. For students only, there is a 15.7% improvement in direct work rate with a physical model instead of 2D drawings and an 18.5% improvement over a 3D model. This, again, reinforces that a simple spatial design is best represented with a physical model.

A similar pattern emerges when looking at indirect work rates, or time spent processing the information format. Practitioners using a physical model spent 12.6% and 18.1% less time reading information than using 2D drawings and a 3D computer model respectively. Students spent 12.9% and 15.6% less time reading information with a physical model than 2D drawings and a 3D computer model respectively.

Finally, there was a significant difference in the delay due to rework (errors) for practitioners in using the physical model versus the 3D computer model. When referencing a physical model, practitioners had 1.0% fewer delays due to errors that were made compared to a 3D computer model.

Combining the information for the direct work, indirect work, and delay due to rework rates, it becomes evident that practitioners and students alike interpret spatial information better with a physical model than with 2D drawings or a 3D computer model.

6.1.2. Practitioners Disconnect Between Task Performance, Preferences, and Scenario-based Selection

From the previous Section 6.1.1, it was found that practitioners and students alike had positive objective outcomes from the experiment using a physical model over 2D drawings and a 3D computer model. Both practitioners and students spent more time performing value-adding activities and less time reading and understanding the given information format. However, when asked which model would they prefer to complete the task, only 39% of practitioners suggested that they would use a physical model, while 46% preferred the 2D drawings. Students had a better self-awareness where 46% suggested the use of a physical model, compared to 27% for both 2D drawings and a 3D computer model. Finally when presented with several real construction tasks, 58% of practitioners and 64% of students would prefer to use a 3D computer model.

Practitioners' responses indicate a disconnect between their performance, their perceived performance, and their perceived application of information formats. This becomes a strong barrier to successfully implementing an information delivery strategy that strays from the typical set of construction drawings. Practitioners still maintain a strong desire to have information presented in the format that has been for decades. Combine that with limited ability to manipulate a computer model and their desire to use a computer model on significant construction tasks, there is a need to address cultural issues behind the perceptions of technology for field use. Many practitioners echoed a negative sentiment towards any format that requires more technical skills.

6.1.3. Issues in 3D Modeling Navigation for Practitioners and 2D Drawing Interpretation for Students

While practitioners expressed a preference for using 3D models for certain construction tasks, there are significant performance barriers towards implementing a strategy involving field models. Section 5.3.3 showed that practitioners consistently required the most cognitive demand from the 3D computer model. In addition, objective performance with the 3D computer model was inferior to that of the physical model and 2D drawings.

Observation results showed that practitioners struggled to navigate the computer model. Several became “stuck” in the model, where the zoom function was overly used to the point where the model was no longer discernible, and the individuals could not recover. There were also others that could not rotate the model to match the orientation of their work platform. That led to the subjects rotating the work platform to equal the orientation of the computer model, which is a process that is unlikely to be replicable in a field setting. The experiment utilized a simple structure and a two function approach to navigating the computer model (a rotate function and a zoom function). Therefore, the required task involved little technical skills to manipulate the model appropriately. The models used in the industry involve more complex structures with many layers of information as well as significantly more controls and on-screen options. For effective use of a 3D computer model by field personnel, there will have to be significant investments made in training as well as addressing the cultural barrier that practitioners have towards high tech tools. The industry currently struggles to attract and maintain skilled workers and having to make large investments in training may not be cost efficient. A physical model, either handmade or 3D printed, may provide the necessary information from a computer model without the required training and learning curve.

The student sample resulted in similar findings but had better outcomes with the 3D computer model instead of the 2D drawings. Students were more functional and comfortable with the 3D computer model from an objective outcome and cognitive demand perspective. This is likely due to their familiarity in a digital environment. However, the current state of the industry values construction drawing creation and interpretation. Since several of the student outcomes found that 2D drawings performed worse than a physical model or 3D computer model, there are some opportunities to improve upon drawing interpretation in the civil engineering curriculum.

6.2. Research Contributions

With the previous results and conclusions, there are several contributions to the body of knowledge that deduced.

1. Presenting the cognitive principles behind spatial information processing allows for a better understanding of how the end user interprets information. Without this understanding, there are limited improvements that can be made towards better information delivery.
2. By testing practitioners on their ability to use 2D drawings, a 3D computer model, and physical model to complete a task, practitioner’s performance with each format is better understood. There is a difference in practitioners’ time spent on interpreting information and on value-adding activities. This research helps identify sources of inefficiency from formats of information delivery.

3. Results from practitioner testing provide quantitative and qualitative evaluations of performance with 3D modeling software. As mobile and field technologies evolve, this research helps show that practitioners need training for effective implementation and application of these tools.
4. From the results and literature review, this research presents the concept of task dependent information formats. Based on the construction tasks at hand, there will be strengths and weaknesses associated with 2D, 3D, and physical formats. With this understanding, field information can be presented in a format(s) that leverages the least cognitive demand and greatest opportunity for understanding.

6.3. Research Limitations

While the presented research makes a significant contribution to the body of knowledge in construction engineering and cognitive psychology research, there are several limitations to state. The model used for testing in this research is a simple spatial structure to focus on the cognitive interpretation of spatial information. This means the results on performance of model types is limited to representation of spatial information. While this is an important takeaway and major component drawing composition, engineering information is a broader subject than solely space.

In addition, the process for 3D printing included in this form may be a time and cost deterrent to application. The simple model used in this study required approximately 30 hours to print and cost approximately $100 in material costs. Further, current BIM modeling techniques do not convert conveniently to a 3D printable model file. The printers require that the model have closed surfaces that are triangulated and have outward facing normal. These properties are not default outcomes from typical BIM modeling processes. It would require extra effort and knowledge on the modeler’s behalf. 3D printers with the necessary capabilities to represent a construction model would cost upwards of $30,000. Many of these 3D printers have print areas in the area of 10”x10”x15”. This footprint is often not large enough to print a full building model from a BIM file. Alternatives would include narrowing in on specific areas of the project or printing the full model in a modular nature with finishing efforts to adhere the elements together. Depending on the use of the 3D model, this may or may not be a concern. These printers also have the ability to print an element as thin as 0.004”. This dimension likely is sufficient for many of the key elements to a printed model, however, some details may be not this large especially if the full model is scaled to fit down in the print area of most printers.

6.4. Opportunities for Future Research

This type of basic, experimental research is limited in the construction engineering body of knowledge, which provides a great opportunity for growth, both in depth and breadth. Further, the information deliverable issued to the construction field has been in the same format for many decades, there is an opportunity to leverage the significant advancements in technology to improve upon the deliverables. In addition, there is also little research conducted in regards to cognitive abilities and cognitive task demands of construction practitioners. In an industry with plenty of environmental distractions and noise, a better understanding of cognition and its effect on individual construction workers and a construction project can add significant value to the body of knowledge. Subsequently, there are several recommendations for additional research.

1. Continue the application of mental workload measurement to real construction tasks. Studying individual trade's mental workload requirement during typical tasks will present clear cut areas for improvement (is the task too physically demanding? Too mentally demanding? Does it require too much effort and/or frustration?).
2. Identify real use of 3D computer and physical models. This research shows the importance of understanding tasks prior to selecting a display format, however, there is upfront work required to understand how 3D and physical models can be presented for field use. These opportunities are quickly emerging through tablets, wearable computers, and 3D printers.
3. Continue research and development of understanding the end user's need for information. Sophisticated CAD and display technologies have allowed for enormous amounts of spatial data and properties to be stored, and impactful application of this information can be developed. By understanding the need, perhaps by trade, 3D modeling software can be developed to export model views in 2D, 3D interface, or physically printed based on the specific task.
4. Between perceptions and performance, there are barriers to effective dissemination of new forms of technologically drive information formats. Identification of these barriers, as well as a methodical approach to addressing the issues would provide value towards adoption.
5. This research begins the process of understanding how end users decode spatial engineering information in various message formats. From an understanding of the communication process, work that begins to understand

how designers encode messages can also improve on errors and issues with engineering drawing management.

In summary, there are differences in spatial information interpretation between practitioners and students based on the information format (two dimensional drawings, a three dimensional computer model, and a physical model). A better understanding of the needs and cognitive demand of practitioners can help significantly increase project communication, productivity, and ultimately, the industry's performance.

APPENDICES

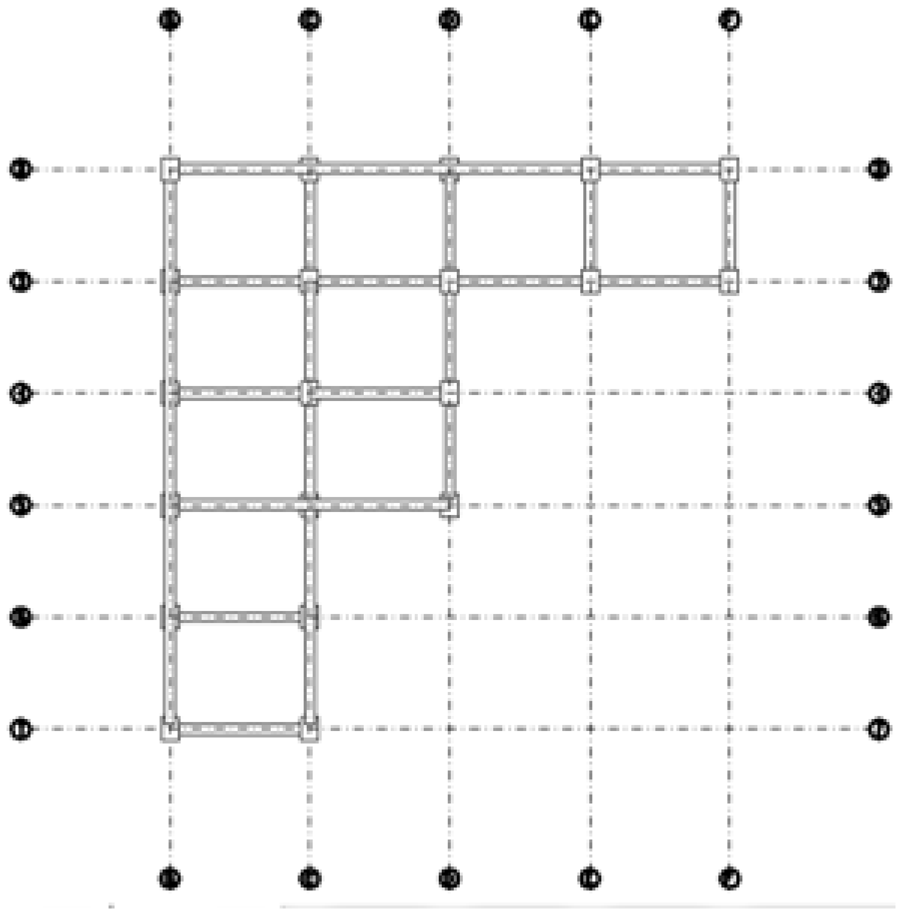
Appendix A: 2D Drawing Set for Model Building

2D Drawing Set for Model Building

Researcher: Gabriel B. Dadi

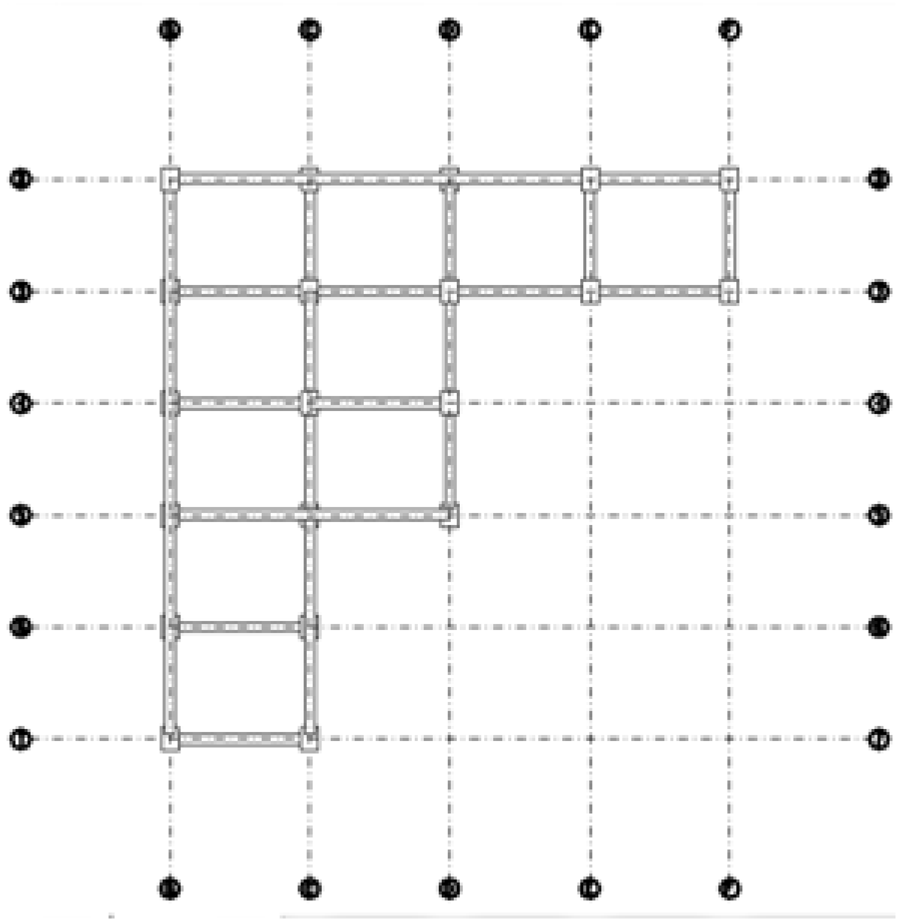
Cover Page

S1



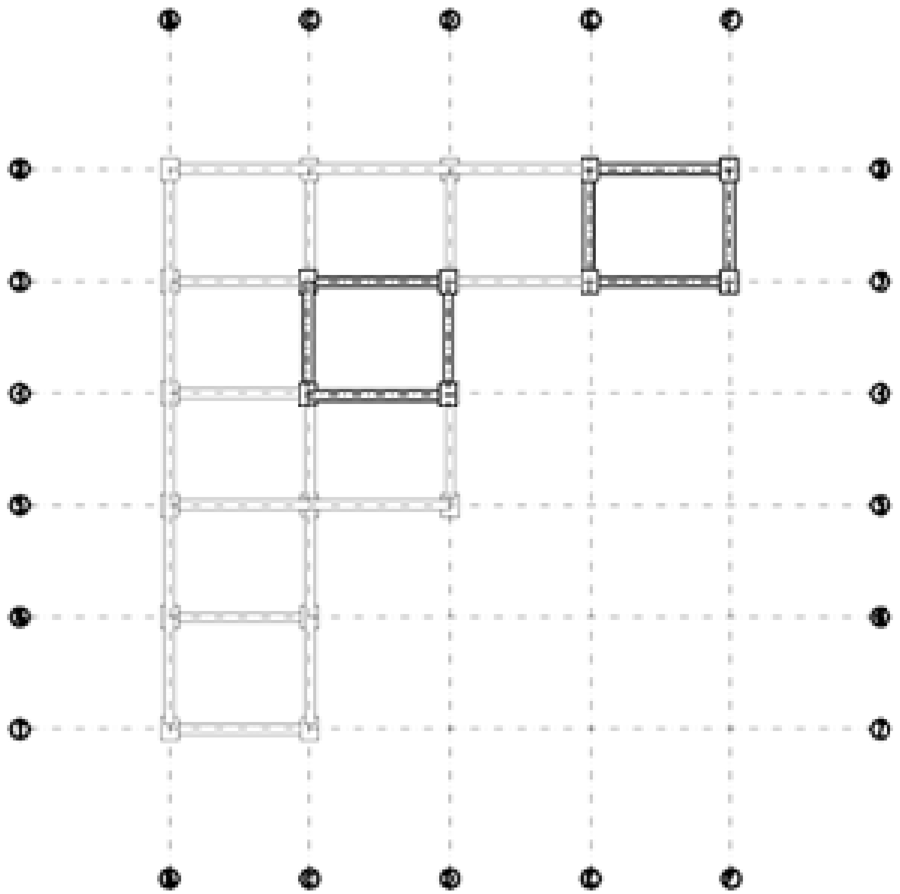
First Floor Plan

S-101



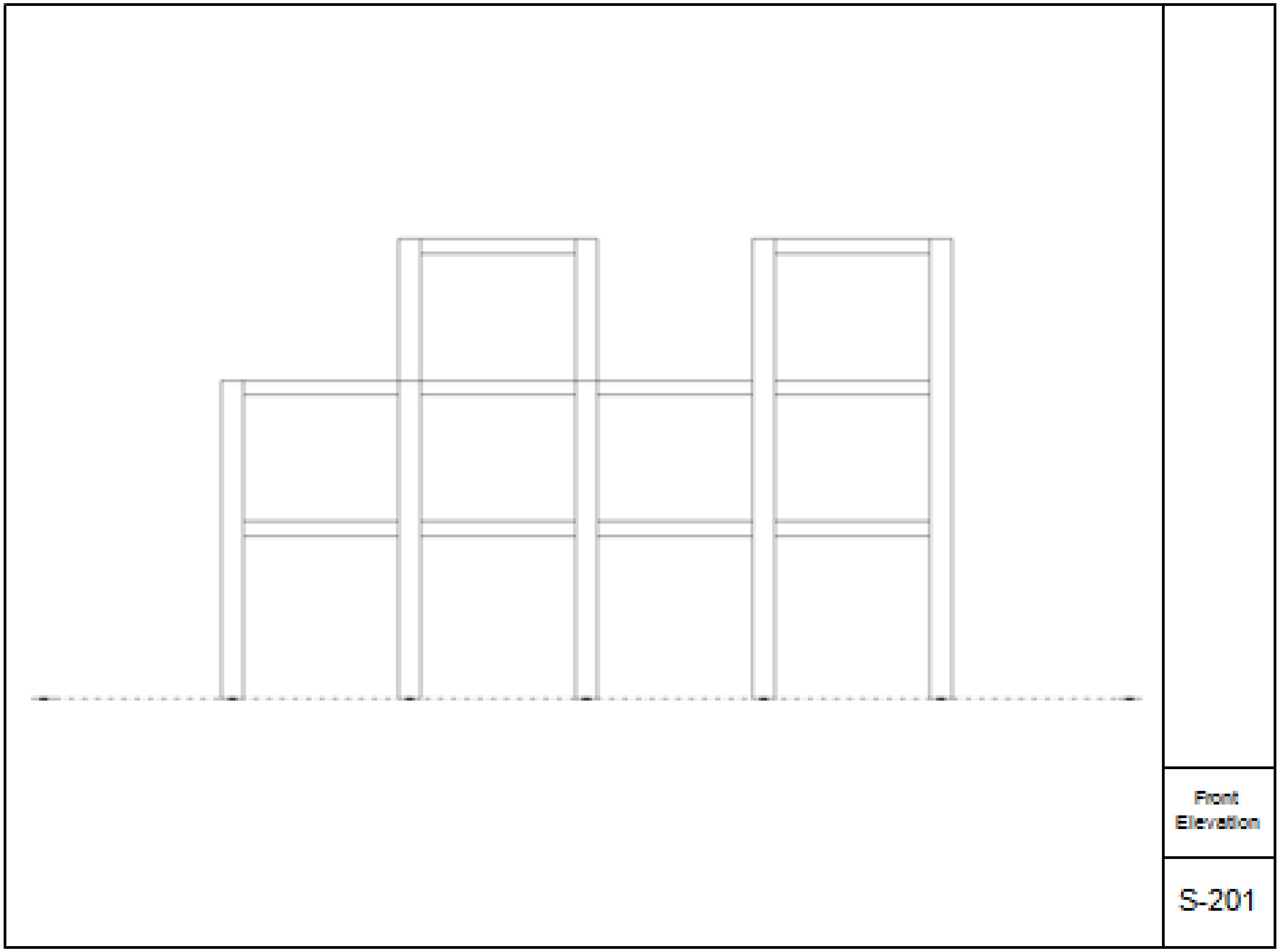
Second
Floor
Plan

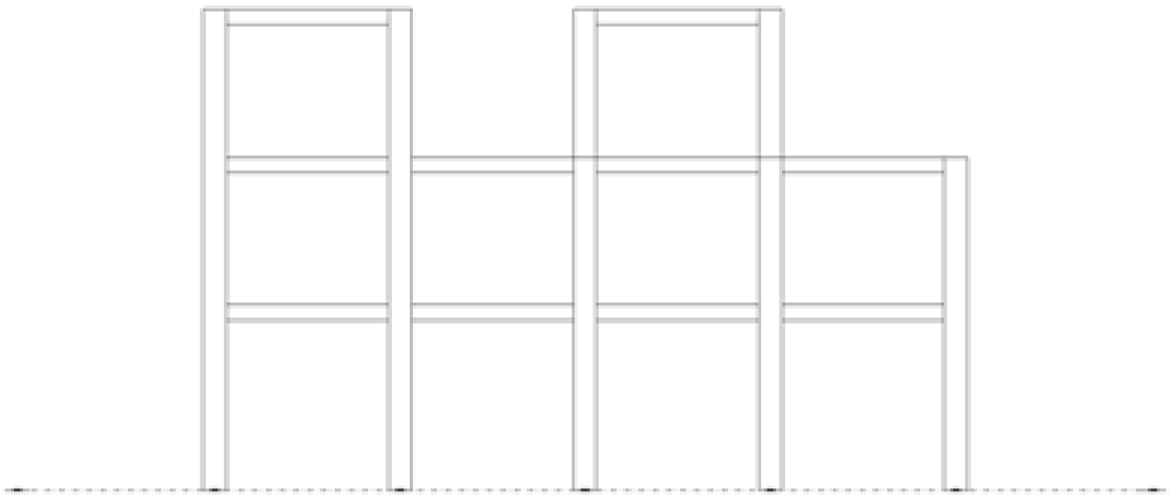
S-102



Third
Floor
Plan

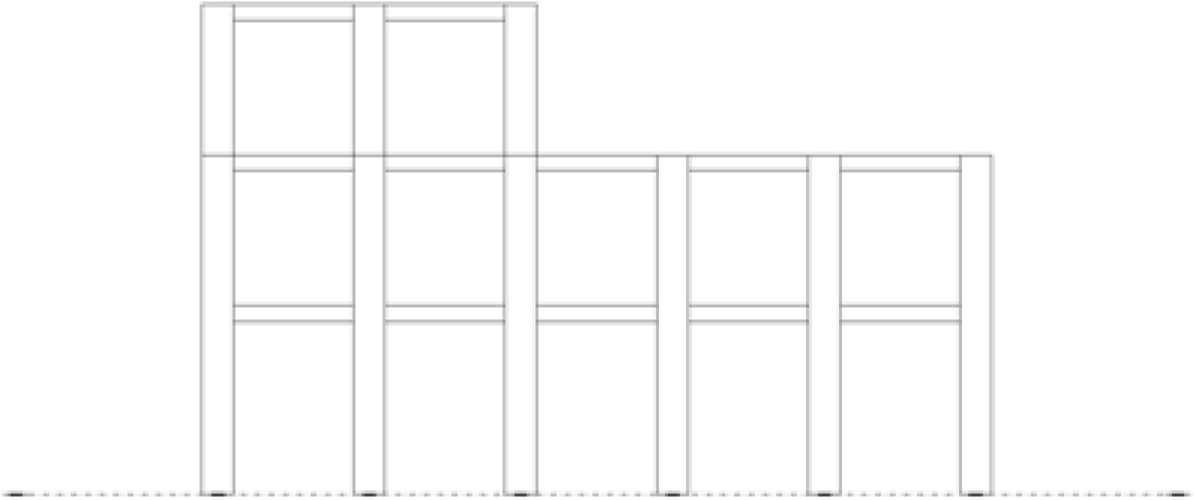
S-103


Front Elevation
S-201



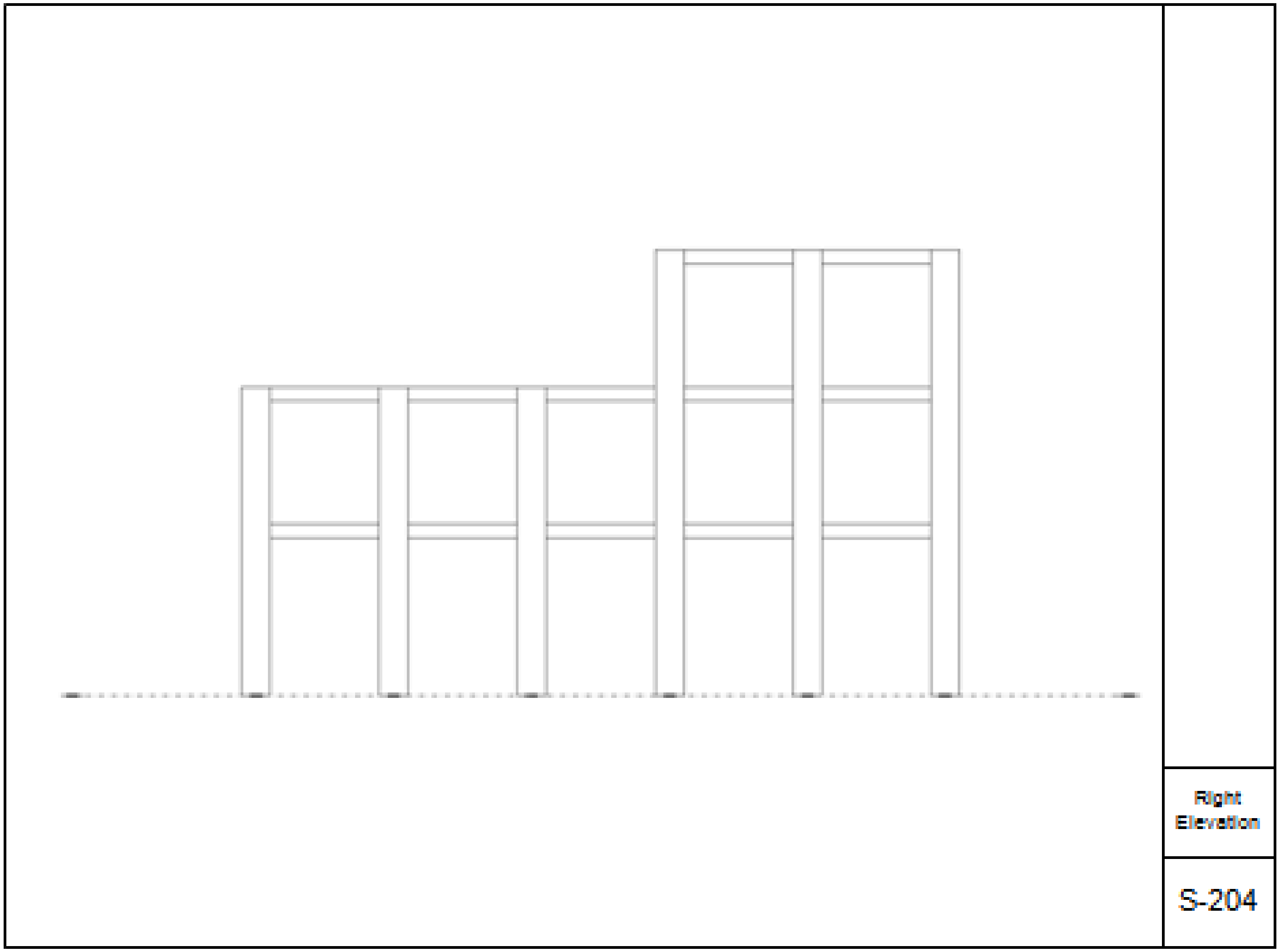
Back Elevation

S-202



Left Elevation

S-203


Right Elevation
S-204

Appendix B: Demographic Questionnaire

Demographic Questionnaire

I have signed the Informed Consent Form agreeing to participate in this study, "Applying Cognitive Principles to the Delivery of Engineering Information by Different Mediums", that has been approved by the Office of Research Integrity at the University of Kentucky. I understand that my responses to this questionnaire are voluntary and that I can choose not to answer certain questions. Furthermore, I understand that I will not be identified by name in any research or publications resulting from this study.

First Name: ____________________________________

Last Name: ____________________________________

Signature: ______________________________________

Date: ___________

Contact Information

Email: ___________________

Phone: ___________________

Preferred Contact Method (if necessary): Email/Phone (Please circle one)

Demographic Information

Age: ___________________

Gender: _________________

Work Experience

Current Occupation (circle one):

Undergraduate StudentGraduate StudentConstruction Worker Other: ___________

Years of Engineering Experience: __________________________

Type of Engineering Experience (circle one):

Intern/Co-opAssistant Engineer/EITEngineer/PESenior Engineer

Years of Construction Experience: __________________________

Frequency in Referencing Construction Drawings (circle one):

DailyVery OftenSometimesRarelyNever

Type of Construction Experience (circle one):

Intern/Co-op   Project Engineer   Project Manager   Craft   Foreman

Superintendent

Other: __________

Education Background (skip if not applicable):

Approximate number of coursework hours completed towards your degree:

____

Please check all civil engineering courses completed below:

___ CE 106 – Computer Graphics and Communication

___ CE 120 – Introduction to Civil Engineering

___ CE 211 – Surveying

___ CE 303 – Introduction to Construction Engineering

___ CE 331 – Transportation Engineering

___ CE 341 – Introduction to Fluid Mechanics

___ CE 351 – Introduction to Environmental Engineering

___ CE 381 – Civil Engineering Materials I

___ CE 382 – Structural Analysis

___ CE 401 – Seminar

___ CE 403 – Construction Methodology

___ CE 429 – Civil Engineering Systems Design

___ CE 461G – Water Resources Engineering

___ CE 471G – Soil Mechanics

___ CE 482 – Elementary Structural Design

___ CE 486G – Reinforced Concrete Structures

___ CE 487G – Steel Structures

Appendix C: Five-Minute Rating Template (Date and PII redacted)

"Applying Cognitive Principles to the Delivery of Engineering Information by Different Mediums" 5-Minute Rating Form

Time	Direct Work	Indirect Work	Rework	Delay due to rework	Comments
0:30		1			
1:00		1			
1:30		1			
2:00		1			
2:30	1				
3:00		1			
3:30		1			
4:00	1				
4:30		1			
5:00	1				
5:30	1				
6:00		1			
6:30	1				
7:00	1				
7:30		1			
8:00	1				
8:30		1			
9:00		1			
9:30	1				

Date:		**PII:**	

Totals		**Percent**
Units	32	100.00%
Direct	14	43.75%
Indirect	15	46.88%
Rework	3	9.38%
Delay	0	0.00%

Notes: Subject had a difficult and uncomfortable time with the computer model. Actually rotated the building model to match what was on the computer screen because he was unable to manipulate the computer model effectively

10:00			1		
10:30			1		
11:00	1				
11:30	1				
12:00	1				
12:30	1				
13:00	1				
13:30		1			
14:00		1			
14:30			1		
15:00		1			
15:30	1				
16:00		1			
Total	14	15	3	0	

Appendix D: NASA-rTLX Form

NASA-rTLX Mental Workload Rating Scale

Please place an “X” along each scale at the point that best indicates your experience with the display configuration.

<u>Mental Demand</u>: How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc)? Was the mission easy or demanding, simple or complex, exacting or forgiving?

Low High

<u>Physical Demand</u>: How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the mission easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

Low High

<u>Temporal Demand</u>: How much time pressure did you feel due to the rate or pace at which the mission occurred? Was the pace slow and leisurely or rapid and frantic?

Low High

<u>Performance</u>: How successful do you think you were in accomplishing the goals of the mission? How satisfied were you with your performance in accomplishing these goals?

Low High

<u>Effort</u>: How hard did you have to work (mentally and physically) to accomplish your level of performance?

Low High

<u>Frustration</u>: How discouraged, stressed, irritated, and annoyed versus gratified, relaxed, content, and complacent did you feel during your mission?

Low High

Appendix E: Post-Test Questionnaire

Post Test Questionnaire

I have signed the Informed Consent Form agreeing to participate in this study, “Applying Cognitive Principles to the Delivery of Engineering Information by Different Mediums”, that has been approved by the Office of Research Integrity at the University of Kentucky. I understand that my responses to this questionnaire are voluntary and that I can choose not to answer certain questions. Furthermore, I understand that I will not be identified by name in any research or publications resulting from this study.

Information Delivery Formats

Please circle the appropriate response for each statement below.

2D Drawing Set is my preferred information delivery format for spatial information.

Strongly Disagree DisagreeUncertainAgree Strongly Agree

A 3D Interface is my preferred information delivery format for spatial information.

Strongly Disagree DisagreeUncertainAgree Strongly Agree

A physical model is my preferred information delivery format for spatial information.

Strongly Disagree DisagreeUncertainAgree Strongly Agree

Why do you prefer the information delivery format from Question 1?

____

____

Consider the following scenarios and answer accordingly:

You are a structural steel subcontractor and need to plan and present an erection sequence, which information delivery format(s) would you use to complete the task (2D, 3D Interface, Physical Model)?

☐ 2D Drawing Set ☐ 3D Interface (Computer monitor) ☐ Physical Model

Why?

____

____

If you are calculating the necessary cubic yards of concrete for an upcoming slab pour, which information delivery format(s) would you use to complete the task (2D, 3D Interface, Physical Model)

☐ 2D Drawing Set ☐ 3D Interface (Computer monitor) ☐ Physical Model

Why?

____

____

If you are a mechanical, electrical, or plumbing engineer and need to design piping runs with sufficient access space, which information delivery format(s) would you use to complete the task (2D, 3D Interface, Physical Model)?

☐ 2D Drawing Set ☐ 3D Interface (Computer monitor) ☐ Physical Model

Why?

If you are estimating the quantity of earthwork that will have to be cut and/or filled on a project, which information delivery format(s) would you use to complete the task (2D, 3D Interface, Physical Model)?

☐ 2D Drawing Set ☐ 3D Interface (Computer monitor) ☐ Physical Model

Why?

Model Comparison

Considering the physical model that you just completed, is the model displayed on the following page the same or different?

If the model is different, what are the differences?

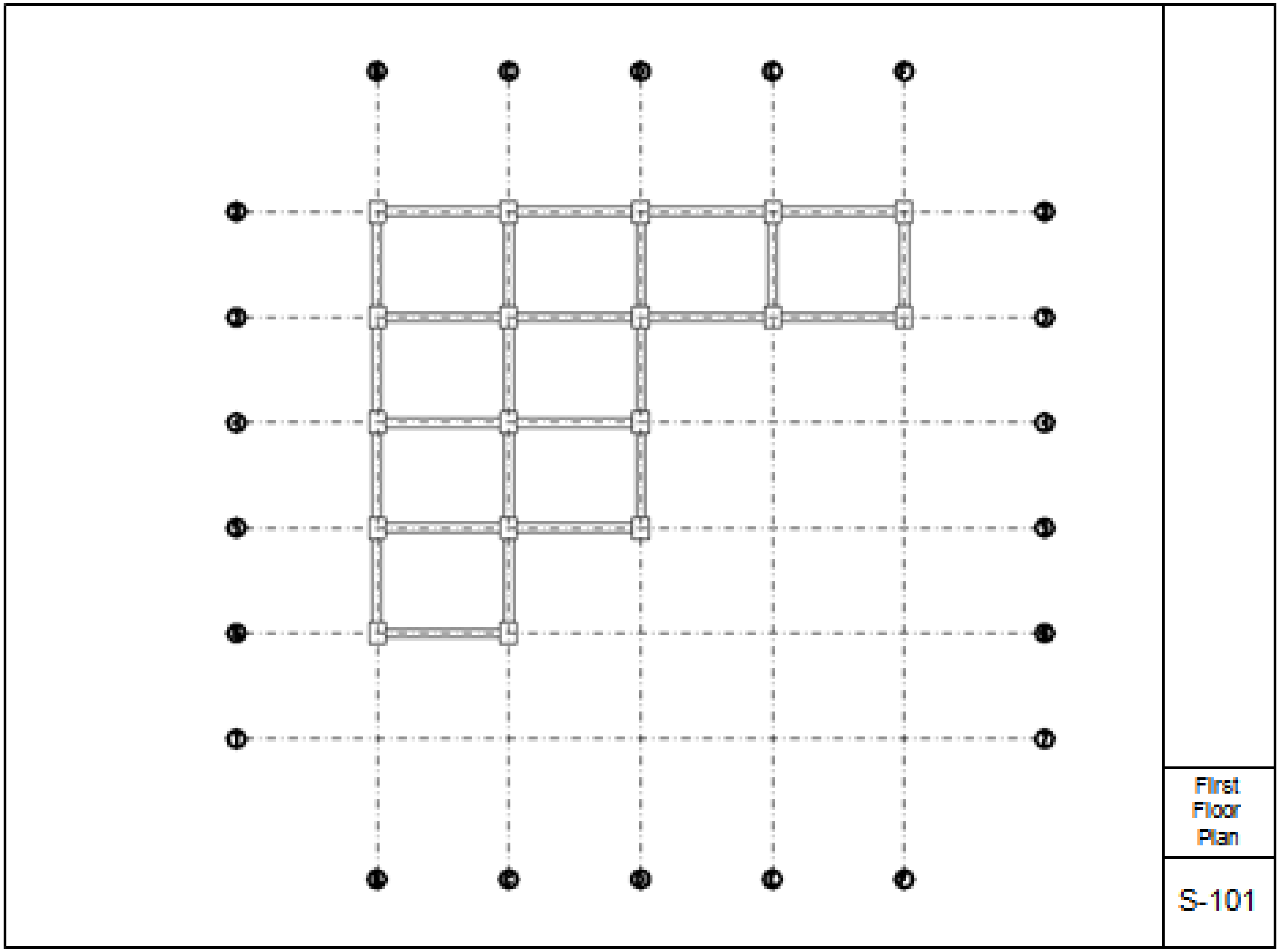
Appendix F: Model Comparison Drawing Set

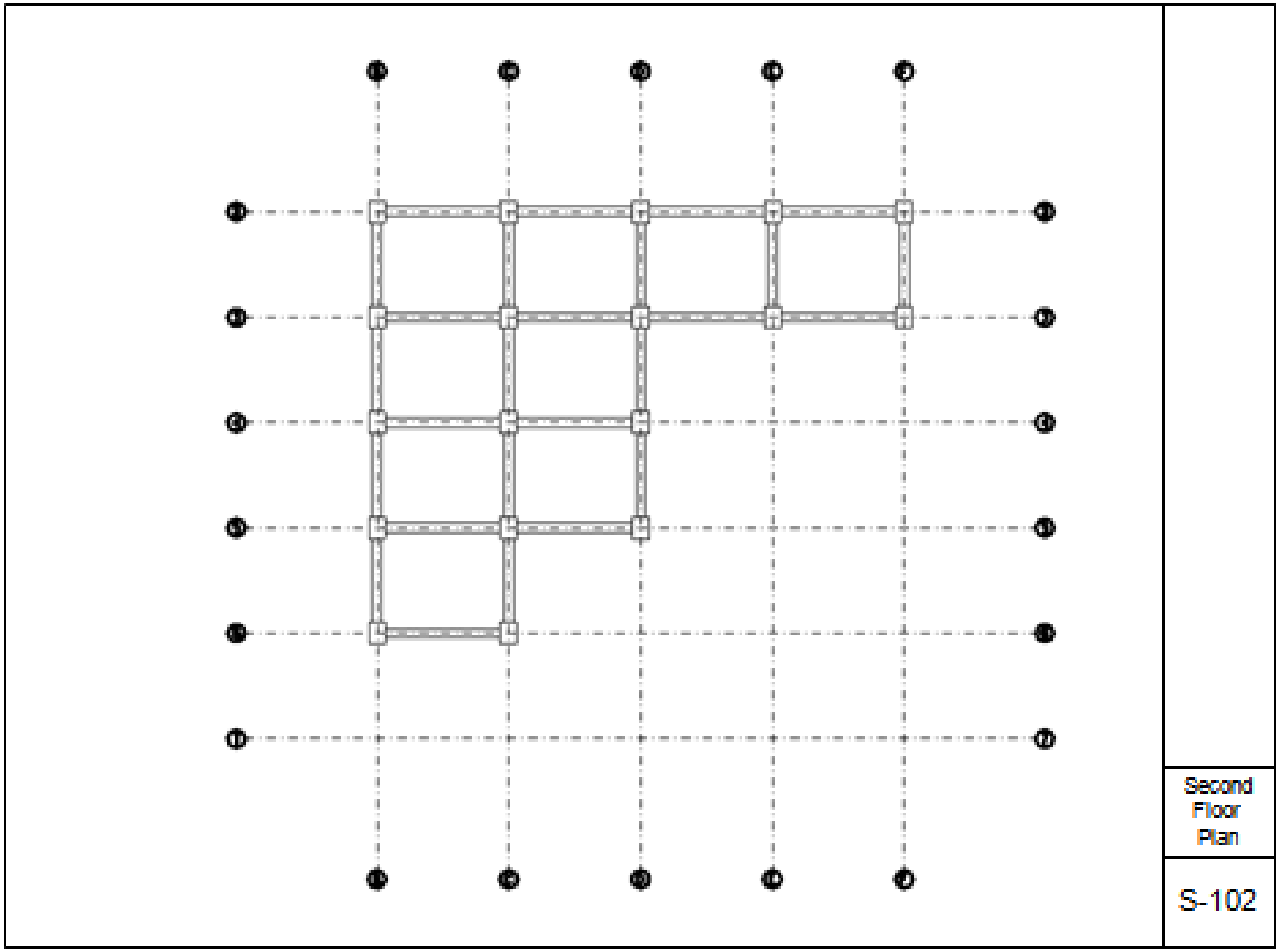
2D Drawing Set for Model Comparison

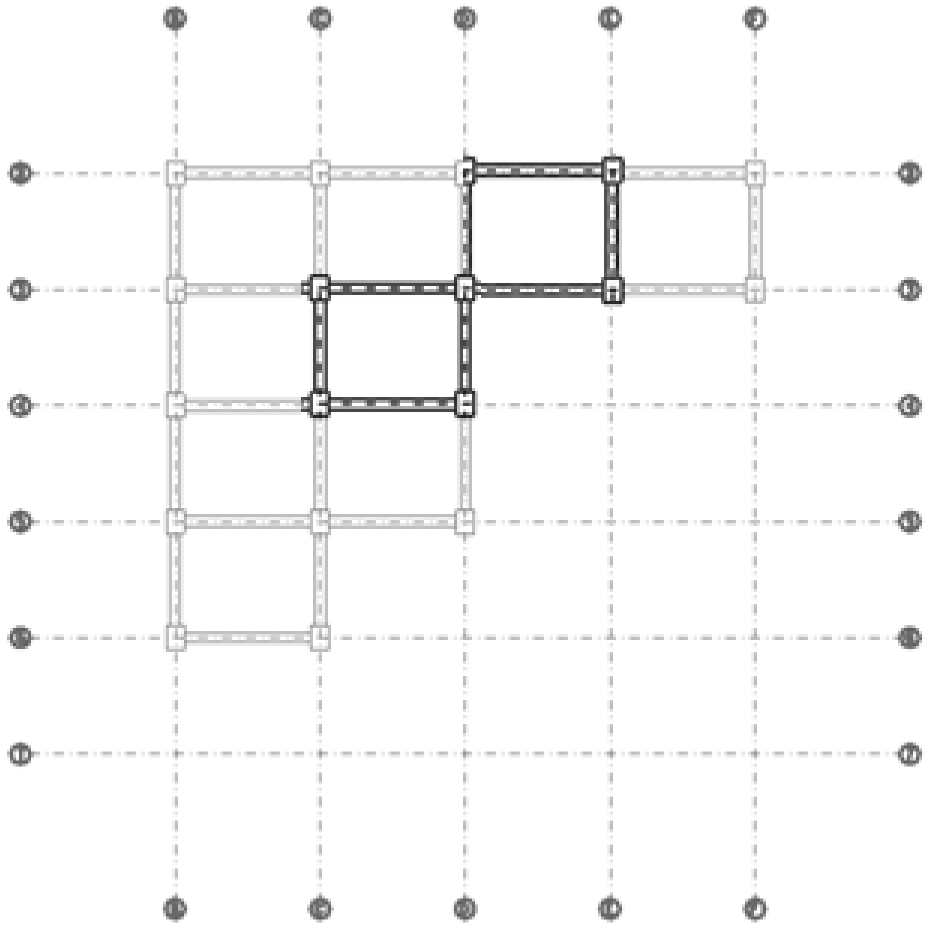
Researcher: Gabriel B. Dadi

Cover Page

S1

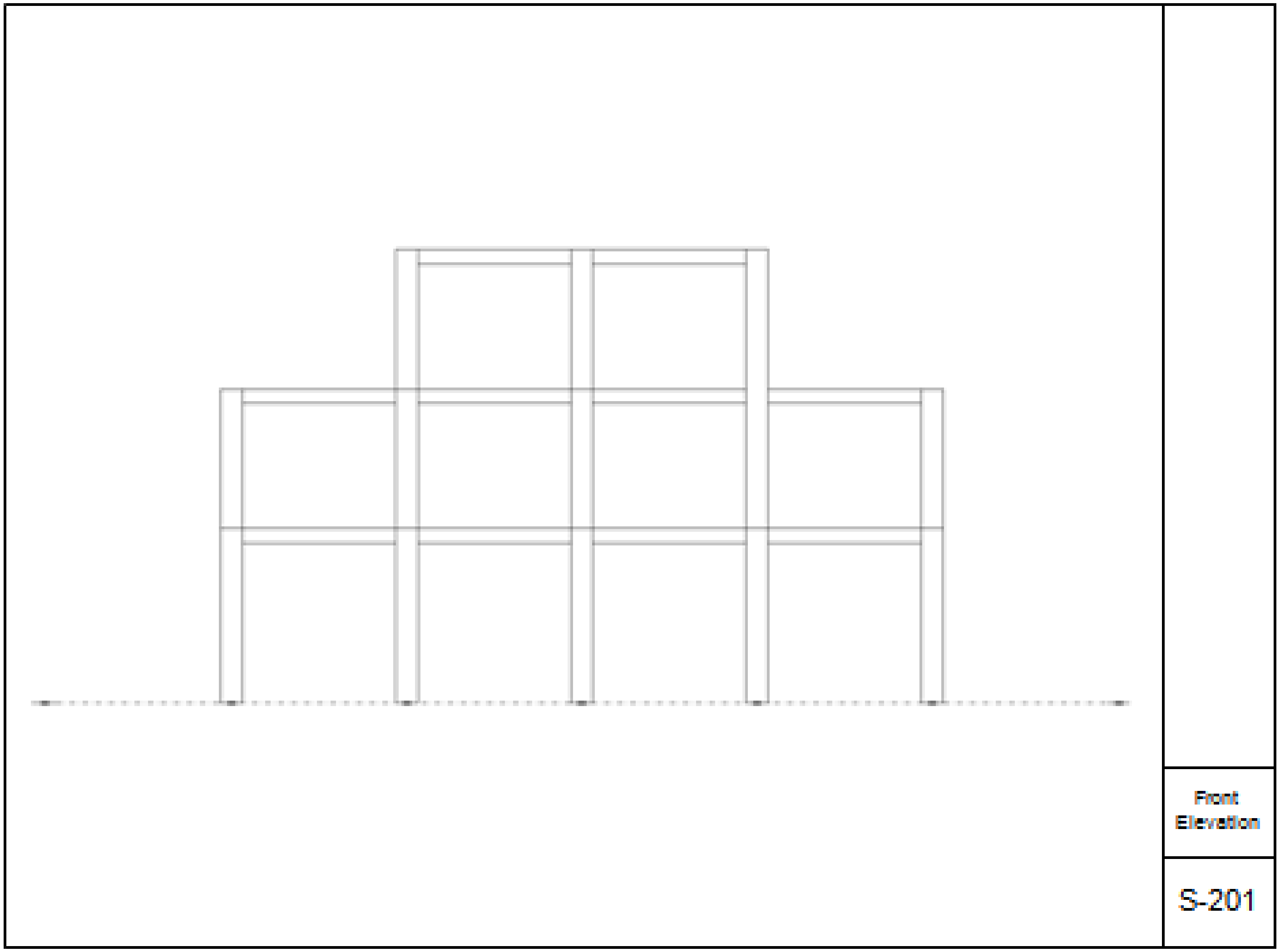

First Floor Plan
S-101

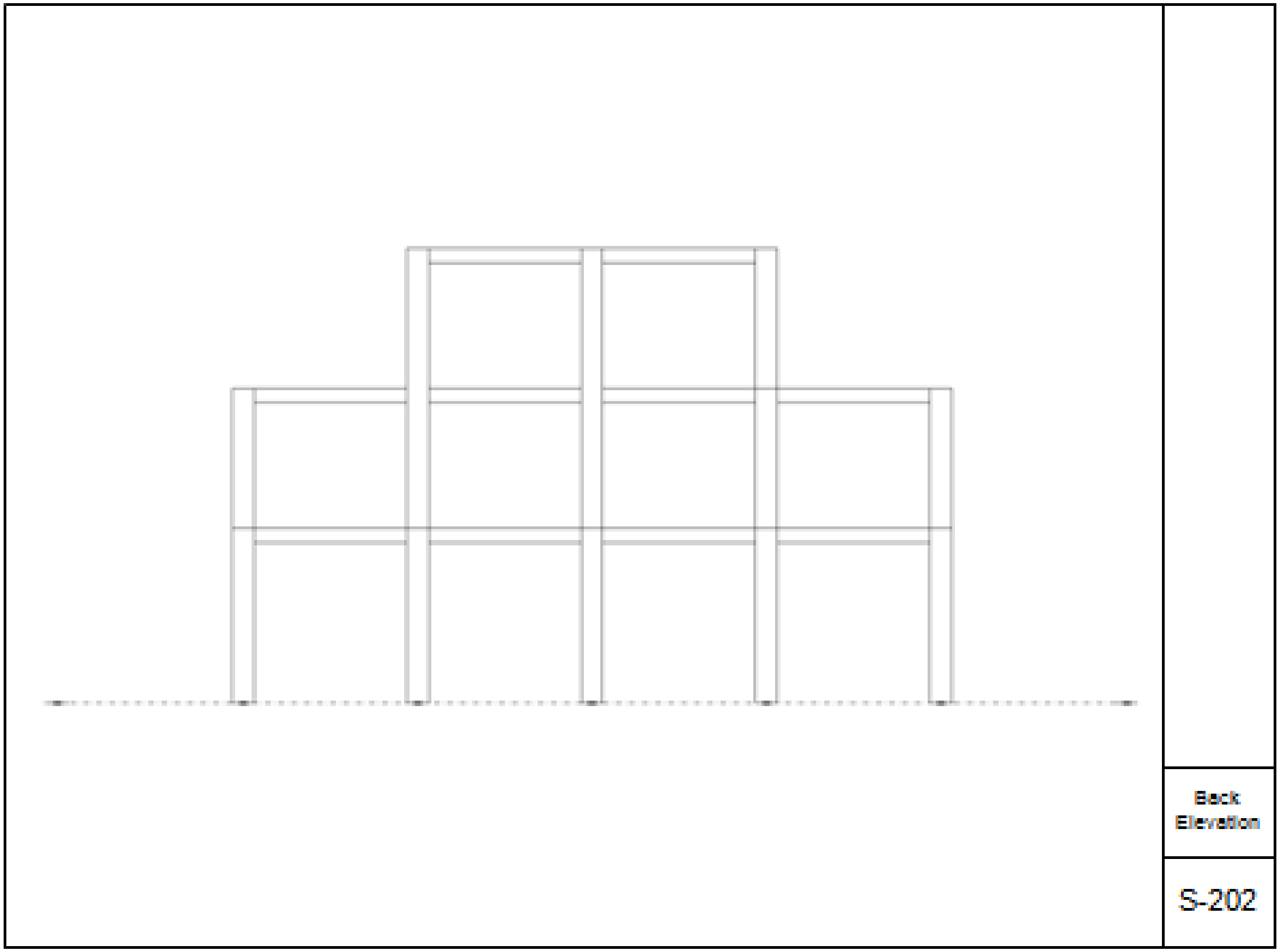

Second
Floor
Plan
S-102

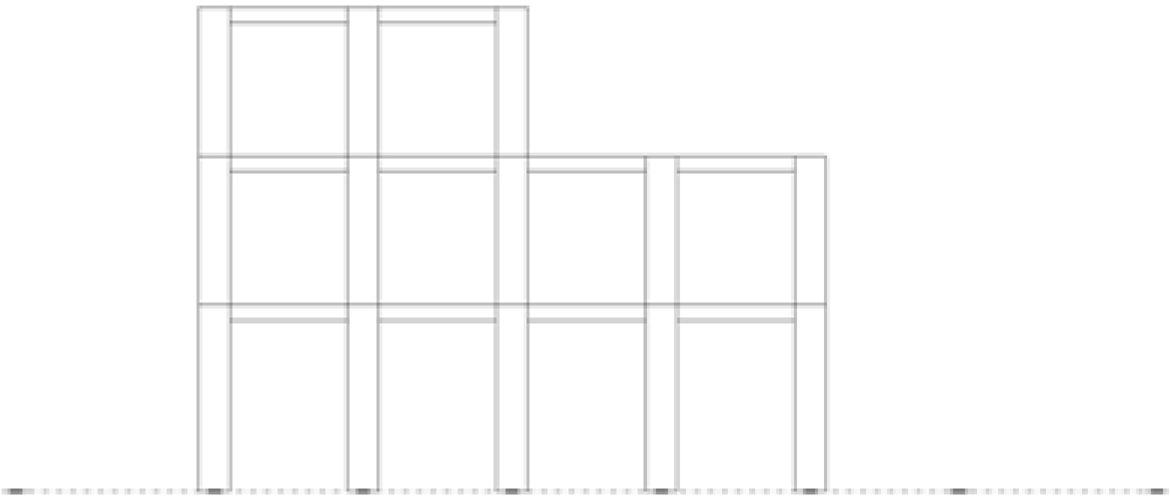


Third
Floor
Plan

S-103

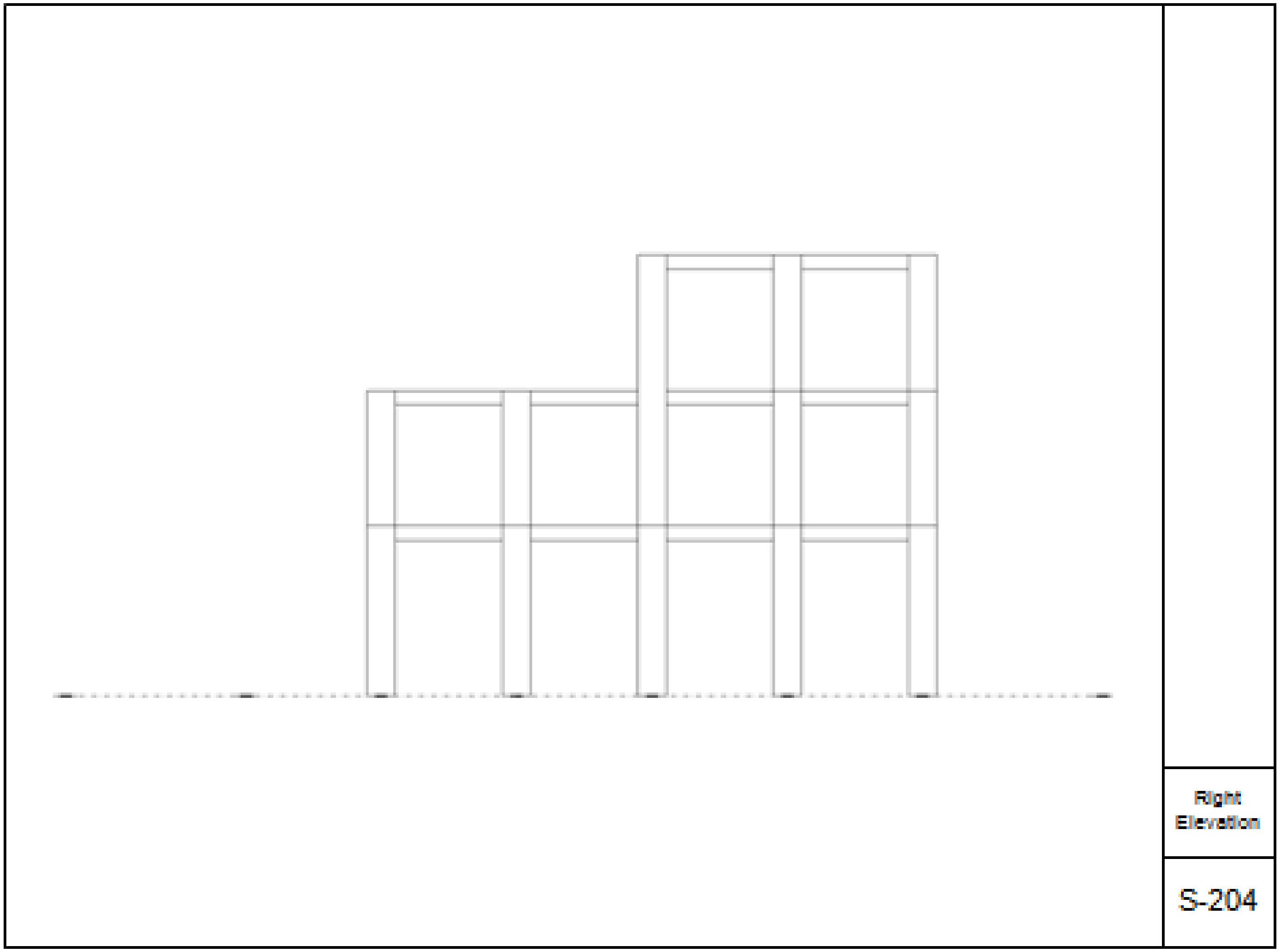

Front Elevation
S-201


Back Elevation
S-202



Left Elevation

S-203


Right Elevation
S-204

FORM A

F2.0050

1.1.1.1.GENERAL INFORMATION SHEET: NONMEDICAL IRB

Appendix G: IRB Submission and Approved Notice

IRB # ______________________

THIS FORM MUST BE TYPED

Note: For best results in opening links contained within this document, it is recommended that you first save this document to the location of your choice. Open the document from that location, then right-mouse click on a link and select "open hyperlink".

This application is described by (check one):

X A. New IRB Research Protocol (Not previously reviewed)

☐ B. Previously Approved Study for which IRB Approval has Lapsed : Previous IRB # ______________

Please include with your submission either a written statement that verifies no research activities (recruitment or enrollment of new subjects; interaction, intervention, or data collection from currently enrolled subjects; or data analysis) have occurred since the lapse in approval, or a summary of events that occurred in the interim.

☐ C. Modification to Currently Approved Protocol

1. Check type of review: Check IRB:
   Expedited X Full: ______ Medical ________ Nonmedical X

2. Name and Address of Principal Investigator (PI) (where mail can most easily reach PI): If research is being submitted to or supported by an extramural funding agency such as NIH, or a private foundation, the PI listed on the grant application must be the same person listed below. If the PI is completing this project to meet the requirements of a University of Kentucky academic program, <u>also</u> list name and campus address of faculty advisor.

PI Name: Gabriel Biratu Dadi ☐ PI is R.N.

Department: Civil Engineering

*Room # & Bldg.: 151D Oliver H. Raymond Building

Speed Sort #: 0281

*Students should list preferred mailing address (i.e., an address where mail will most quickly reach them).

3. PI's AD account : Gbdadi2 Degree and Rank: PhD, doctoral candidate

(*"username" to log in to your UK network account, i.e., jdoe*)

PI's Employee/Student ID#: 910010041 *(Note: If Employee ID# is not available, provide first & last initials with year of birth – e.g., JB1969)*

PI's Telephone #: 502-314-8798 Dept. Code:

PI's e-mail address: Gabe.dadi@uky.edu PI's FAX Number:

4. Title of Project: (If applicable, use the exact title listed in the grant/contract application. **When applicable to your research, it is important that you add to the beginning of your title the following: "UK/P" if your research involves prisoners; "UK/D" if your research is supported by the Department of Defense".**

Applying Cognitive Principles to the Delivery of Engineering Information by Different Mediums

5. Indicate which of the categories listed below accurately describes this protocol:

☒ Not greater than minimal risk

☐ Greater than minimal risk, but presenting the prospect of direct benefit to individual subjects

☐ Greater than minimal risk, no prospect of direct benefit to individual subjects, but likely to yield generalizable knowledge about the subject's disorder or condition

☐ Research not otherwise approvable which presents an opportunity to understand, prevent, or alleviate a serious problem affecting the health or welfare of subjects

6. Anticipated Beginning and Ending Date of Research Project: 06/01/2012 (Month/Day/Year) / 04/01/2013 (Month/Day/Year)

7. Number and age level of human subjects: 25 (Number) / 21-65 (Age Range)

8. Indicate the categories of subjects and controls to be included in the study. You may be required to complete additional forms depending on the subject category applicable to your research. Check ALL that apply:

☐ Children (17 yrs or less) [attach Form W]
☐ Wards of the State [attach Form W]
☐ Emancipated Minors
☐ Impaired Consent Capacity [attach Form T]
☐ Impaired Consent Capacity (Institutionalized) [attach Form T]
☐ Neonates [attach Form U]
☐ Pregnant Women [attach Form U]
☐ Military Personnel [DoD SOP may apply]

☐ Prisoners [attach Form V]
☐ Non-English Speaking [see Form H info (HTML)]
☐ International Citizens [DoD SOP may apply]
☒ Students
☐ Normal Volunteers
☐ Patients
☐ Appalachian Population

9. Does this study focus on subjects with any of the clinical conditions listed below that present a high likelihood of impaired consent capacity or fluctuations in consent capacity?

X No - skip to question 10

☐ Yes

If yes, does the research involve interaction or intervention with subjects?

☐ No, direct intervention/interaction is not involved (e.g., record-review research, secondary data analysis) -skip to question 10

☐ Yes - direct intervention/interaction is involved - complete and attach **Form T** to your IRB application.

Examples of such conditions include:

- *Traumatic brain injury or acquired brain injury*
- *Severe depressive disorders or Bipolar disorders*
- *Schizophrenia or other mental disorders that involve serious cognitive disturbances*
- *Stroke*
- *Developmental disabilities*
- *Degenerative dementias*
- *CNS cancers and other cancers with possible CNS involvement*
- *Late stage Parkinson's Disease*
- *Late stage persistent substance dependence*
- *Ischemic heart disease*
- *HIV/AIDS*
- *COPD*
- *Renal insufficiency*
- *Diabetes*
- *Autoimmune or inflammatory disorders*
- *Chronic non-malignant pain disorders*
- *Drug effects*
- *Other acute medical crises*

10. Indicate the targeted/planned enrollment of the following members of minority groups and their subpopulations [**Please note: the IRB will expect this information to be reported at Continuation Review time**]:

Ethnic Origin	# Male	# Female	Ethnic Origin	# Male	# Female
American Indian/ Alaskan Native			Hispanic/Latino		
Asian			Native Hawaiian/Pacific Islander		
Black/African			White/Caucasian		

American		

Other or unknown	25	

11. Indicate the items below that apply to your research. Depending on the items applicable to your research, you may be required to complete additional forms or meet additional requirements. Contact the ORI (859-257-9428) if you have questions about additional requirements. Check ALL that apply.

- ☒ Academic Degree / Required Research
- ☐ Aging Research
- ☐ Alcohol Abuse Research
- ☐ **Cancer Research**
- ☐ Certificate of Confidentiality
- ☐ CR-DOC (Clinical Research Development & Operations Center)
- ☐ Clinical Research
- ☐ Clinical Trial
  - ☐ Multicenter Clinical Trial (excluding NIH Cooperative Groups)
  - ☐ NIH cooperative groups (i.e., SWOG, RTOG)
  - ☐ Placebo Controlled Trial
  - ☐ UK only
- ☐ Data & Safety Monitoring Board
- ☐ Data & Safety Monitoring *Plan*
- ☐ Deception [attach Form E]
- ☐ Drug/Substance Abuse Research
- ☐ Educational/Student Records (e.g., GPA, test scores)
- ☐ Genetic Research
- ☐ NIH GWAS (Genome-Wide Association Study)
- ☐ UK HIPAA Authorization
- ☐ UK HIPAA Waiver of Authorization
- ☐ UK HIPAA De-Identification
- ☐ HIV/AIDS Research
- ☐ HIV Screening
- ☐ International Research [see Form H info (HTML)]
- ☐ Internet Research
- ☐ Psychology Dept. Subject Use & Research Ethics (SURE) Committee
- ☒ Survey Research
- ☐ Waiver of Informed Consent [attach Form E]
- ☐ Waiver of Requirement for Documentation of Informed Consent [attach Form F]

12. If the research is being submitted to, supported by, or conducted in cooperation with an external or internal funding program, indicate the categories that apply. Check ALL that apply:

☒ Not applicable
☐ (HHS) Dept. of Health & Human Services
  - ☐ (NIH) National Institutes of Health
  - ☐ (CDC) Centers for Disease Control & Prevention
  - ☐ (HRSA) Health Resources and Services Administration
  - ☐ (SAMHSA) Substance Abuse and Mental Health Services Administration

☐ Federal Agencies Other Than Those Listed Here
☐ Industry (Other than Pharmaceutical Companies)
☐ Internal Grant Program
☐ National Science Foundation
☐ Other Institutions of Higher Education
☐ Pharmaceutical Company
☐ Private Foundation/Association
☐ State
☐ U.S. Department of Education

13. Specify the funding source and/or cooperating organization(s): (e.g., Dept. Of Education, National Institute on Aging, Ford Foundation, Bureau of Prisons, U.S. Department of Justice, etc.) **If your project is funded, please see Form AA in Section 6 of the IRB application for applicability of attachments.**

Independently funded

14. ☐ Yes X No The research is supported by the Department of Defense (DoD).
If yes, attach to your IRB application materials addressing the specific processes described in the Department of Defense IRB/ORI Coordination SOP

[http://www.research.uky.edu/ori/human/SOPs_&_Policies.htm#6].

15. a) Check all the applicable sites listed below at which the research will be conducted. **If you check any of the non-UK sites, see IRB application Section 4, Form N for a description of additional materials required with your application submission.**

☐ Not applicable
☐ Bluegrass Regional Mental Health Retardation Board
☐ Cardinal Hill Hospital
☐ Correctional Facilities
☐ Eastern State Hospital
☐ Fayette Co. School Systems
☐ Home Health Agencies
☐ Institutions of Higher Education (other than UK)
☐ International Sites
☐ Nursing Homes
☐ Other Hospitals and Med. Centers
☐ Other State/Regional School Systems
☐ Shriner’s Children’s Hospital
☒ UK Classroom(s)/Lab(s)
☐ UK Clinics in Lexington
☐ UK Clinics outside Lexington
☐ UK Healthcare Good Samaritan Hospital
☐ UK Hospital
☐ Other: ______________________________

b) Is this a multi-site study for which you are the lead investigator? Yes X No

______ ______

c) Is this a multi-site study for which the University of Kentucky is the lead site? Yes X No

______ ______

If yes to b and/or c, additional information must be provided to the UK IRB in the applicable section of Form N.

Note: You may also need to include Form N if any of your study personnel are not an employee or student of the University of Kentucky (see Question #19).

16. Disclosure of Financial Interest:

a) All investigators and employees who are or will be responsible for the design, conduct, or reporting of activities under **externally-funded** research at the University of Kentucky are required to complete a **Research Financial Interest Disclosure Statement (RFIDS)** [http://www.uky.edu/eForms/forms/discfin.pdf]. Have you, or any of the specified personnel who completed a **Research Financial Interest Disclosure Statement (RFIDS)** (Form X), answered "yes" to ANY of the 8 questions on the form?

______ Yes ______ No __X__ Not externally-funded

b) **If your study is *not externally-funded***, complete Form Y [**Research Financial Interest Disclosure Statement (RFIDS)** (for non-externally funded research)] and include it with your application submission.

If “yes” on either Form X or Form Y, you must include with your IRB application submission a copy of the *completed* form (Form X/RFIDS), **and** if you have completed the Research Conflict of Interest Committee review, a copy of the final approved management plan. If you do not have a final approved management plan, contact the Office of Sponsored Projects Administration (OSPA). Note: The management plan must be submitted to the IRB before it can issue its final approval.

17. Additional Certification: (If your project is federally funded, your funding agency may request an Assurance/Certification/Declaration of Exemption form.) Check the following if needed:

☐ Protection of Human Subjects Assurance/Certification/Declaration of Exemption (Formerly Optional Form – 310)

18. Identify other STUDY personnel assisting in research project (**attach additional sheets if necessary**). (In the space provided, specify which personnel are authorized by the principal investigator to obtain informed consent.) NOTE: Study personnel are required to receive human research protection training before implementing any research procedures (e.g., "Dunn & Chadwick", CITI). For information about mandatory training requirements for study personnel, read UK's "Education Requirement for Investigators and Study Personnel Involved with Human Subjects Research" available at: http://www.research.uky.edu/ori/human/Human_Research_Mandatory_Education.htm or contact ORI at 859-257-9428.

    If you are using this sheet to request changes in study personnel (SP) that have not been previously reported to the IRB, please include with your Modification Request Form two copies of a current list of **all** study personnel, denoting the changes.

    *If the research is being completed to meet academic requirements, the faculty advisor is also considered study personnel.

Note: If Employee ID# or Student ID# is not available, provide first & last initials with year of birth – e.g., JB1969

A) Study personnel assisting in research project:

1.1.2. FORM A

F2.0050

1.1.3.GENERAL INFORMATION SHEET: NONMEDICAL IRB

UK Affiliated individuals assisting in research project as study personnel:	**NON-UK Affiliated** individuals assisting in research project as study personnel [Form N may need to be included i
Name, Paul McGinley Goodrum,	Name, Rank/Degree ______
Responsibility in Faculty Advisor	Responsibility in ______
E-mail address: pgoodrum@engr.uky.edu	E-mail address: ______
Employee/Student ______	Employee/Student ID#: ______
Authorized to Obtain Consent: X Yes ___ No	Authorized to Obtain Consent___ Yes ___ No
Mandatory Training X Yes ___ No	Mandatory Training ___ Yes ___ No
Name, ______	Name, Rank/Degree ______
Responsibility in ______	Responsibility in ______
E-mail address: ______	E-mail address: ______
Employee/Student ______	Employee/Student ID#: ______
Authorized to Obtain Consent: ___ Yes ___ No	Authorized to Obtain Consent___ Yes ___ No
Mandatory Training ___ Yes ___ No	Mandatory Training ___ Yes ___ No
Name, ______	Name, Rank/Degree ______
Responsibility in ______	Responsibility in ______
E-mail address: ______	E-mail address: ______
Employee/Student ______	Employee/Student ID#:
Authorized to Obtain Consent: ___ Yes ___ No	Authorized to Obtain Consent___ Yes ___ No
Mandatory Training ___ Yes ___ No	Mandatory Training ___ Yes ___ No
Name, ______	Name, Rank/Degree ______
Responsibility in ______	Responsibility in ______
E-mail address: ______	E-mail address: ______
Employee/Student ______	Employee/Student ID#: ______
Authorized to Obtain Consent: ___ Yes ___ No	Authorized to Obtain Consent___ Yes ___ No
Mandatory Training ___ Yes ___ No	Mandatory Training ___ Yes ___ No

IRB # 12-0303-P4S

THIS FORM MUST BE TYPED

Note: For best results in opening links contained within this document, it is recommended that you first save this document to the location of your choice. Open the document from that location, then right-mouse click on a link and select "open hyperlink".

This application is described by (check one):

☐ A. New IRB Research Protocol (Not previously reviewed)

☐ B. Previously Approved Study for which IRB Approval has Lapsed : Previous IRB # __________

Please include with your submission either a written statement that verifies no research activities (recruitment or enrollment of new subjects; interaction, intervention, or data collection from currently enrolled subjects; or data analysis) have occurred since the lapse in approval, or a summary of events that occurred in the interim.

X C. Modification to Currently Approved Protocol

6. Check type of review: Expedited X Full: ____ Check IRB: Medical ____ Nonmedical X

7. Name and Address of Principal Investigator (PI) (where mail can most easily reach PI): If research is being submitted to or supported by an extramural funding agency such as NIH, or a private foundation, the PI listed on the grant application must be the same person listed below. If the PI is completing this project to meet the requirements of a University of Kentucky academic program, also list name and campus address of faculty advisor.

PI Name: Gabriel Biratu Dadi and Dr. Timothy R.B. Taylor (faculty advisor) ☐ PI is R.N.

Department: Civil Engineering

*Room # & Bldg.: 151D Oliver H. Raymond Building (Dadi) and 151A Oliver H. Raymond Building (Taylor)

Speed Sort #: 0281

*Students should list preferred mailing address (i.e., an address where mail will most quickly reach them).

8. PI's AD account : Gbdadi2 Degree and Rank: PhD, doctoral candidate

(*"username" to log in to your UK network account, i.e., jdoe*)

PI's Employee/Student ID#: 910010041

(Note: If Employee ID# is not available, provide first & last initials with year of birth – e.g., JB1969)

PI's Telephone #: 502-314-8798

Dept. Code:

PI's e-mail address: Gabe.dadi@uky.edu

PI's FAX Number:

7. Title of Project: (If applicable, use the exact title listed in the grant/contract application. **When applicable to your research, it is important that you add to the beginning of your title the following: "UK/P" if your research involves prisoners; "UK/D" if your research is supported by the Department of Defense".**

   Applying Cognitive Principles to the Delivery of Engineering Information by Different Mediums

8. Indicate which of the categories listed below accurately describes this protocol:

☒ Not greater than minimal risk

☐ Greater than minimal risk, but presenting the prospect of direct benefit to individual subjects

☐ Greater than minimal risk, no prospect of direct benefit to individual subjects, but likely to yield generalizable knowledge about the subject's disorder or condition

☐ Research not otherwise approvable which presents an opportunity to understand, prevent, or alleviate a serious problem affecting the health or welfare of subjects

9. Anticipated Beginning and Ending Date of Research Project: 06/01/2012 / 04/01/2013

Month/Day/Year Month/Day/Year

8. Number and age level of human subjects: 50 / 18-65

Number Age Range

19. Indicate the categories of subjects and controls to be included in the study. You may be required to complete additional forms depending on the subject category applicable to your research. Check ALL that apply:

☐ Children (17 yrs or less) [attach Form W]
☐ Wards of the State [attach Form W]
☐ Emancipated Minors
☐ Impaired Consent Capacity [attach Form T]
☐ Impaired Consent Capacity (Institutionalized) [attach Form T]
☐ Neonates [attach Form U]
☐ Pregnant Women [attach Form U]
☐ Military Personnel [DoD SOP may apply]

☐ Prisoners [attach Form V]
☐ Non-English Speaking [see Form H info (HTML)]
☐ International Citizens [DoD SOP may apply]
☒ Students
☐ Normal Volunteers
☐ Patients
☐ Appalachian Population

20. Does this study focus on subjects with any of the clinical conditions listed below that present a high likelihood of impaired consent capacity or fluctuations in consent capacity?

X No - skip to question 10

☐ Yes

If yes, does the research involve interaction or intervention with subjects?

☐ No, direct intervention/interaction is not involved (e.g., record-review research, secondary data analysis) -skip to question 10

☐ Yes - direct intervention/interaction is involved - complete and attach **Form T** to your IRB application.

Examples of such conditions include:

- *Traumatic brain injury or acquired brain injury*
- *Severe depressive disorders or Bipolar disorders*
- *Schizophrenia or other mental disorders that involve serious cognitive disturbances*
- *Stroke*
- *Developmental disabilities*
- *Degenerative dementias*
- *CNS cancers and other cancers with possible CNS involvement*
- *Late stage Parkinson's Disease*
- *Late stage persistent substance dependence*
- *Ischemic heart disease*
- *HIV/AIDS*
- *COPD*
- *Renal insufficiency*
- *Diabetes*
- *Autoimmune or inflammatory disorders*
- *Chronic non-malignant pain disorders*
- *Drug effects*
- *Other acute medical crises*

21. Indicate the targeted/planned enrollment of the following members of minority groups and their subpopulations [**Please note: the IRB will expect this information to be reported at Continuation Review time**]:

Ethnic Origin	# Male	# Female	Ethnic Origin	# Male	# Female
American Indian/ Alaskan Native			Hispanic/Latino		
Asian			Native Hawaiian/Pacific Islander		

Black/African American		

White/Caucasian		
Other or unknown	50	

22. Indicate the items below that apply to your research. Depending on the items applicable to your research, you may be required to complete additional forms or meet additional requirements. Contact the ORI (859-257-9428) if you have questions about additional requirements. Check ALL that apply.

- ☒ Academic Degree / Required Research
- ☐ Aging Research
- ☐ Alcohol Abuse Research
- ☐ **Cancer Research**
- ☐ Certificate of Confidentiality
- ☐ CR-DOC (Clinical Research Development & Operations Center)
- ☐ Clinical Research
- ☐ Clinical Trial
  - ☐ Multicenter Clinical Trial (excluding NIH Cooperative Groups)
  - ☐ NIH cooperative groups (i.e., SWOG, RTOG)
  - ☐ Placebo Controlled Trial
  - ☐ UK only
- ☐ Data & Safety Monitoring Board
- ☐ Data & Safety Monitoring *Plan*
- ☐ Deception [attach Form E]
- ☐ Drug/Substance Abuse Research
- ☐ Educational/Student Records (e.g., GPA, test scores)
- ☐ Genetic Research
- ☐ NIH GWAS (Genome-Wide Association Study)
- ☐ UK HIPAA Authorization
- ☐ UK HIPAA Waiver of Authorization
- ☐ UK HIPAA De-Identification
- ☐ HIV/AIDS Research
- ☐ HIV Screening
- ☐ International Research [see Form H info (HTML)]
- ☐ Internet Research
- ☐ Psychology Dept. Subject Use & Research Ethics (SURE) Committee
- ☒ Survey Research
- ☐ Waiver of Informed Consent [attach Form E]
- ☐ Waiver of Requirement for Documentation of Informed Consent [attach Form F]

23. If the research is being submitted to, supported by, or conducted in cooperation with an external or internal funding

program, indicate the categories that apply. Check ALL that apply:

☒ Not applicable
☐ (HHS) Dept. of Health & Human Services
  ☐ (NIH) National Institutes of Health
  ☐ (CDC) Centers for Disease Control & Prevention
  ☐ (HRSA) Health Resources and Services Administration
  ☐ (SAMHSA) Substance Abuse and Mental Health Services Administration
☐ Federal Agencies Other Than Those Listed Here
☐ Industry (Other than Pharmaceutical Companies)
☐ Internal Grant Program
☐ National Science Foundation
☐ Other Institutions of Higher Education
☐ Pharmaceutical Company
☐ Private Foundation/Association
☐ State
☐ U.S. Department of Education

24. Specify the funding source and/or cooperating organization(s): (e.g., Dept. Of Education, National Institute on Aging, Ford Foundation, Bureau of Prisons, U.S. Department of Justice, etc.) **If your project is funded, please see Form AA in Section 6 of the IRB application for applicability of attachments.**

Independently funded

25. ☐ Yes X No The research is supported by the Department of Defense (DoD). **If yes, attach to your IRB application materials addressing the specific processes described in the Department of Defense IRB/ORI Coordination SOP** [http://www.research.uky.edu/ori/human/SOPs_&_Policies.htm#6].

26. a) Check all the applicable sites listed below at which the research will be conducted. **If you check any of the non-UK sites, see IRB application Section 4, Form N for a description of additional materials required with your application submission.**

☐ Not applicable
☐ Bluegrass Regional Mental Health Retardation Board
☐ Cardinal Hill Hospital
☐ Correctional Facilities
☐ Eastern State Hospital
☐ Fayette Co. School Systems
☐ Home Health Agencies
☐ Institutions of Higher Education (other than UK)
☐ International Sites
☐ Nursing Homes
☐ Other Hospitals and Med. Centers
☐ Other State/Regional School Systems
☐ Shriner's Children's Hospital
☒ UK Classroom(s)/Lab(s)
☐ UK Clinics in Lexington
☐ UK Clinics outside Lexington
☐ UK Healthcare Good Samaritan Hospital
☐ UK Hospital
☐ Other: ____________________

b) Is this a multi-site study for which you are the lead investigator? _______ Yes ___X___ No

c) Is this a multi-site study for which the University of Kentucky is the lead site? _______ Yes ___X___ No

If yes to b and/or c, additional information must be provided to the UK IRB in the applicable section of Form N.

Note: You may also need to include Form N if any of your study personnel are not an employee or student of the University of Kentucky (see Question #19).

27. Disclosure of Financial Interest:

a) All investigators and employees who are or will be responsible for the design, conduct, or reporting of activities under **externally-funded** research at the University of Kentucky are required to complete a **Research Financial Interest Disclosure Statement (RFIDS)** [http://www.uky.edu/eForms/forms/discfin.pdf]. Have you, or any of the specified personnel who completed a **Research Financial Interest Disclosure Statement (RFIDS)** (Form X), answered "yes" to ANY of the 8 questions on the form?

______ Yes ______ No ___X___ Not externally-funded

b) **If your study is *not externally-funded***, complete Form Y [**Research Financial Interest Disclosure Statement (RFIDS)** (for non-externally funded research)] and include it with your application submission.

If "yes" on either Form X or Form Y, you must include with your IRB application submission a copy of the *completed* form (Form X/RFIDS), **and** if you have completed the Research Conflict of Interest Committee review, a copy of the final approved management plan. If you do not have a final approved management plan, contact the Office of Sponsored Projects Administration (OSPA). Note: The management plan must be submitted to the IRB before it can issue its final approval.

28. Additional Certification: (If your project is federally funded, your funding agency may request an Assurance/Certification/Declaration of Exemption form.) Check the following if needed:

☐ Protection of Human Subjects Assurance/Certification/Declaration of Exemption (Formerly Optional Form – 310)

29. Identify other STUDY personnel assisting in research project (**attach additional sheets if necessary**). (In the space provided, specify which personnel are authorized by the principal investigator to obtain informed consent.) NOTE: Study personnel are required to receive human research protection training before implementing any research procedures (e.g., "Dunn & Chadwick", CITI). For information about mandatory training requirements for study personnel, read UK's "Education Requirement for Investigators and Study Personnel Involved with Human Subjects Research" available at: http://www.research.uky.edu/ori/human/Human_Research_Mandatory_Education.htm or contact ORI at 859-257-9428.

    If you are using this sheet to request changes in study personnel (SP) that have not been previously reported to the IRB, please include with your Modification Request Form two copies of a current list of **all** study personnel, denoting the changes.

    *If the research is being completed to meet academic requirements, the faculty advisor is also considered study personnel.

Note: If Employee ID# or Student ID# is not available, provide first & last initials with year of birth – e.g., JB1969

B) Study personnel assisting in research project:

UK Affiliated individuals assisting in research project as study personnel:	**NON-UK Affiliated** individuals assisting in research project as study personnel [Form N may need to be included in
Name, Timothy R.B. Taylor, Asst.	Name, Rank/Degree ___
Responsibility in Faculty Advisor	Responsibility in ___
E-mail address: tim.taylor@uky.edu	E-mail address: ___
Employee/Student 10138912	Employee/Student ID#: ___
Authorized to Obtain Consent: _X_ Yes ___ No	Authorized to Obtain Consent: ___ Yes ___ No
Mandatory Training _X_ Yes ___ No	Mandatory Training ___ Yes ___ No
Name, ___	Name, Rank/Degree ___
Responsibility in ___	Responsibility in ___
E-mail address: ___	E-mail address: ___
Employee/Student ___	Employee/Student ID#: ___
Authorized to Obtain Consent: ___ Yes ___ No	Authorized to Obtain Consent: ___ Yes ___ No
Mandatory Training ___ Yes ___ No	Mandatory Training ___ Yes ___ No
Name, ___	Name, Rank/Degree ___
Responsibility in ___	Responsibility in ___
E-mail address: ___	E-mail address: ___
Employee/Student ___	Employee/Student ID#:
Authorized to Obtain Consent: ___ Yes ___ No	Authorized to Obtain Consent: ___ Yes ___ No
Mandatory Training ___ Yes ___ No	Mandatory Training ___ Yes ___ No
Name, ___	Name, Rank/Degree ___
Responsibility in ___	Responsibility in ___
E-mail address: ___	E-mail address: ___
Employee/Student ___	Employee/Student ID#: ___
Authorized to Obtain Consent: ___ Yes ___ No	Authorized to Obtain Consent: ___ Yes ___ No
Mandatory Training ___ Yes ___ No	Mandatory Training ___ Yes ___ No

In approximately 7 typed pages (excluding attached appendices) of font size 10 or larger, describe your protocol using the outline below. Each response should be numbered or labeled to correspond to each of the following items. If an item does not apply to your research project, simply indicate that the question is "not applicable." For the following sections: 1. “Background”; 2. “Objectives”; 3. “Study Design”; and 4. “Study Population,” you may provide a photocopy of the *relevant* passages from the sponsor’s full protocol or grant application. *Note In the Research Description, please make reference to the page number and section and in the appended materials reference the IRB Research Description question and mark the passages (“Background, Objectives, etc.). Attach the relevant passages in order as an appendix to the Research Description. The Research Description should be intelligible to all of the IRB members, professional and lay.

*NOTE: You may also electronically scan the passages from the sponsor’s protocol that address questions 1, 2, 3 and 4 below and cut and paste those passages into your Research Description.

1. **Background:**

   Please see Appendix A for information on the introduction and background of the study from the research proposal.

2. **Objectives:**
   1. Understand the types and uses of information delivery methods
   2. Understand the cognitive principles behind spatial information processing
   3. Identify the capabilities of additive manufacturing technologies
   4. Test subject’s on their ability to use the different mediums
   5. Evaluate and determined the most effective medium for spatial information processing
3. **Study Design:**

   Please see Appendix B from the research proposal concerning the study design including information on subject selection.

4. **Study Population:**

Please see Appendix C from the research proposal for a description of the study population. In addition, the subject population will be civil engineering students at the University of Kentucky that are not under the grading authority of the PIs and construction craft workers. The study is not concerned with including or excluding anyone based on demographics, therefore, the makeup of the subject sample will be random. The subjects will be selected based off of their willingness to participate in the study. The study will only require one two hour session and will not inconvenience the subjects beyond this session.

5. **Subject Recruitment Methods and Privacy**:

The student subjects will be recruited through the use of fliers as seen in the attached Form L. On the flier, the PI's contact information (office, phone number, and email address) is displayed and noted as being the method of initial contact. The flier will be displayed through the Oliver H. Raymond building, which is the primary housing facility for the Department of Civil Engineering. Students under the grading authority of the PIs will not be recruited. The subject's interaction with the PI will be in the form of a briefing prior to the assessments taking place. It will be in the room that the tests will be administered.

The craft subjects will be recruited through a local construction company's work force. The company will allow access and time for the study to take place after typical meetings. The craft subjects will be notified that their participation will enter them into a raffle for a $50 gift card. This announcement will be verbal, and there will be a gift card awarded for every ten participants, giving each subject a 10% chance of winning.

Since there are differences in recruitment, specifically in an entry for an award for participation, there are two versions of form 20150 C "Informed Consent". One is for student subjects, where there is no reward for participating, and another for craft subjects, where it details their entry into a raffle for a gift card. To differentiate the forms, the footer contains a version number. For the craft worker consent form, the footer reads "F2.0150v1". For the student consent form, the footer reads "F2.0150v2".

6. **Informed Consent Process**:

Subjects will be given a copy of form 20150 C “Informed Consent” form as approved by the IRB prior to the test beginning and prior to the beginning of recording. Please see Form 20150C for a copy of the informed consent form. It outlines the research statement, any risks, benefits, alternatives, confidentiality, and compensation for the subjects and contact information for the PI.

The subjects will not be coerced or under undue influence to sign the informed consent form. If a subject decides against signing the informed consent form, they will be immediately removed from the test sample and thanked for their interest in the study. All subjects will be capable of understanding the guidelines put forth by the informed consent form and will be given every opportunity to ask questions and understand the entirety of their participation in the study.

7. **Research Procedures:**

The study is cross-disciplinary in that it relies heavily on cognitive psychology to study the learning and processing of spatial information. The benefits of 2D vs. 3D is well published but is native to 3D interfaces (computer monitors). The study will be adding a haptic dynamic from a 3D printed model. Civil engineering students and craft workers will be asked to complete a cognitive test of their spatial orientation abilities. The tests will be the Card Rotations tests for 2D mental rotations, and the Cube Comparisons tests for 3D mental rotations. Both of these tests are validated and frequently cited assessments for spatial orientation. This will provide a baseline for their spatial ability and performance. The subjects will then be asked to assemble a simple structure using scaled modeling tools. The desired structure will be handed to them in either a 2D drawing set, a 3D BIM model, or the physical model. The subjects will begin and end a timer as they begin and finish the task. Incidences of rework and direct work will be monitored through a videotaping and subsequent analysis. After the task is completed, there is a post-test questionnaire that identifies the amount of mental workload required to complete the task as well as identifying preferences in information displays. All procedures involve no more than minimal risk and are standard in nature.

8. **Resources:**

The study will be conducted in a lab or classroom in the Oliver H. Raymond building on the campus of the University of Kentucky. The building houses the civil engineering program and the students that will be recruited. Sufficient space and supervision (the PI) will exist for assistance. Outside of the testing materials, the only equipment that will be necessary is a video camera and tripod to record the test for later analysis. Since the test is cognitive and involves no more than minimal risk, there will not be a need for psychological, social, or medical services or monitoring.

9. **Potential Risks:**

To the best of our knowledge, the things subjects will be doing have no more risk of harm than one would experience in everyday life. At the conclusion of the study, each subject will be asked to participate in a subjective review of the cognitive loading of each task and other cognitive assessments. Note that their responses to the questionnaire will be used to evaluate the workload required from each of the information delivery formats, as well as their ability to mentally rotate images.

10. **Safety Precautions:**

Subjects' confidentiality will be protected while collecting the data by assigning a random identifier to the collected copies of the test results. When recording the data, the identifier will not be directly noted. The subject will have full privacy during the completion of the study. The PI will be there to orientate the subject and provide the necessary documentation and protocol for the study but will then exit the area to provide privacy to the subject. In addition, the videotaping of the task will be set up to avoid filming any facial identification of the subject. The camcorder will be focused on the task set, which may result in filming portions of the subject's arms as the model is built.

There will not be a need for any medical or professional intervention as the study presents no more than minimal harm, and the study population is not vulnerable.

11. **Benefit vs. Risk:**

The potential benefits are to assisting in a contribution to the body of knowledge of the civil engineering and cognitive psychology research fields. The knowledge gained will be critical to understanding how engineering information can be presented for spatial understanding, which will provide unique and insightful findings to the academic and industry communities.

The risks are no more than minimal. In essence, by participating the probability and magnitude of harm or discomfort anticipated in the research are not greater in and of themselves than those ordinarily encountered in daily life or during the performance of routine physical or psychology examinations or tests.

Since exposure is minimal, the benefits in the study outweigh any potential risk or harm from participation. The study population is not vulnerable.

12. **Available Alternative Treatment(s):**

If a subject does not want to be in the study, there are no other choices except not to take part in the study.

13. **Research Materials, Records, and Privacy:**

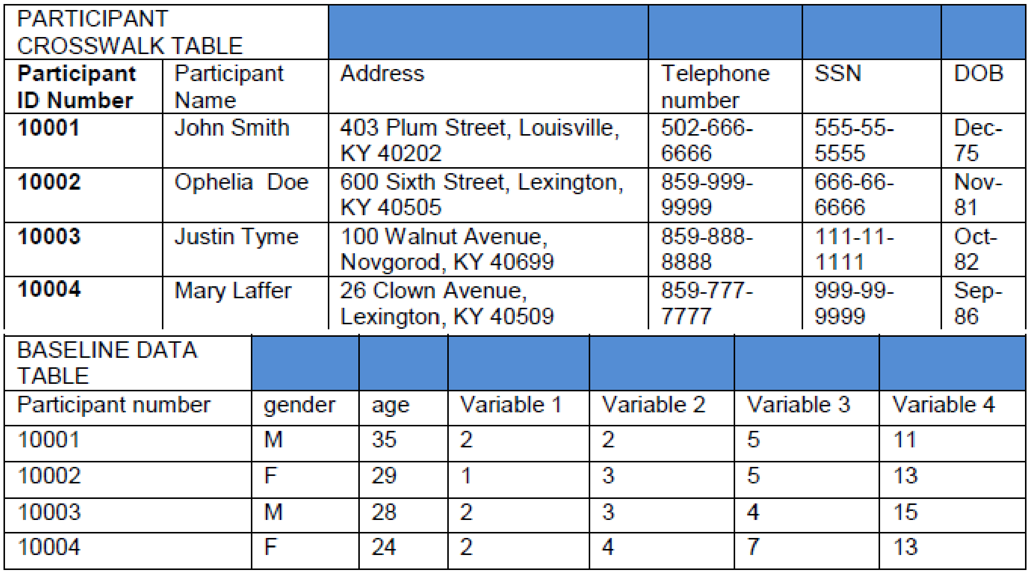
The materials and records that will be kept from the study include a general demographic sheet, responses from a test on spatial rotations, videotape from the task, and responses to a posttest questionnaire.

The demographic sheet will be useful in characterizing the performance of different sample sets. For instance, what is the effect of years of engineering experience on an individual's ability to interpret spatial information from a certain format? The spatial rotations responses will identify the natural ability of individuals to understanding the display formats that will be tested. This will tell the researchers if certain individuals are more inclined to perform the task better due to their natural spatial ability. The posttest questionnaires will identify the level of mental workload required to complete the task and individual preferences for the information display formats. This information will tell the researchers which information delivery format requires the most loading to complete and also if one format is preferred over another. The videotape will be necessary to identify what percent of time, during the task completion, was spent actually completing the structure versus waiting or making and correcting errors. The researchers will use that information to identify which information delivery format results in the least amount of errors while interpreting the information. All of the information will be considered together to ultimately draw conclusions from the study.

There will be no record of any existing specimens, records, or data.

14. Confidentiality:

The paper based data (informed consent, demographic sheet, tests, and questionnaire) will be stored in a locked drawer, in a locked office of the investigator for at least six years. The office is 151D Oliver H. Raymond Building on the campus of the University of Kentucky. The data will have a random number identifier that is consistent across the data for an individual. A Personal Identifying Information (PII) will be assigned to the study participants and will be associated in a separate electronic file as seen in the sample crosswalk below.



PARTICIPANT CROSSWALK TABLE					
Participant ID Number	Participant Name	Address	Telephone number	SSN	DOB
10001	John Smith	403 Plum Street, Louisville, KY 40202	502-666-6666	555-55-5555	Dec-75
10002	Ophelia Doe	600 Sixth Street, Lexington, KY 40505	859-999-9999	666-66-6666	Nov-81
10003	Justin Tyme	100 Walnut Avenue, Novgorod, KY 40699	859-888-8888	111-11-1111	Oct-82
10004	Mary Laffer	26 Clown Avenue, Lexington, KY 40509	859-777-7777	999-99-9999	Sep-86

BASELINE DATA TABLE						
Participant number	gender	age	Variable 1	Variable 2	Variable 3	Variable 4
10001	M	35	2	2	5	11
10002	F	29	1	3	5	13
10003	M	28	2	3	4	15
10004	F	24	2	4	7	13

While the concept of the above table will be applied, the data collected will differ. For instance, there will be no need to collect individual's social security numbers or addresses. The study will ask for a name and contact phone number. The electronic data file will be saved on a password protected University owned laptop in the locked office of the investigator. No unauthorized person will be allowed to access the drawer or the computer account. Once the six year timeframe passes, the paper based data will be shredded in a paper shredder of the approved standard for permanent destruction of the data.

In addition, video recording of this task will be taken and be saved onto the same computer under the PII number. Once the video file is uploaded to the designated computer, any remaining files on the video recorder or memory card will be immediately deleted. As previously mentioned, care will be taken to ensure that only necessary portions of the task be videotaped (i.e. the actual task completion, not the subject).

15. **Payment**:

The subjects will be recruited under a voluntary concept with no payment or tangible incentive. They will be asked to volunteer their time to help complete a study that advances the knowledge base of science in civil engineering.

16. **Costs to Subjects**:

    There are no costs associated with taking part in the study, other than your time.

17. **Data and Safety Monitoring:**

    The research is not exposing subjects to greater than minimal risk, is not clinical research, nor is it NIH-funded.

18. **Subject Complaints:**

    Subjects will be provided with the PI's contact information including office phone number, email address, and office location. The subjects will be welcome to contact the PI with any complaints they may have on a confidential basis. In addition, the subjects will be advised that they can contact the PI's faculty advisor. While the research is a requirement for an academic degree, (requiring the faculty advisor as an individual on the research protocol) the advisor will not be present while data is collected. In addition, the subjects are always welcome to contact the University of Kentucky's Office of Research Integrity (IRB).

18. **Research Involving Non-English Speaking Subjects or Subjects from a Foreign Culture:**

    Not applicable

20. **HIV/AIDS Research:**

    Not applicable

APPENDIX A – Background (Excerpt from Research Proposal)

Background and Motivation

Construction industry spending is annually one of the largest sector contributions to the gross domestic product (GDP) in the United States. In 2010, the industry was responsible for more than $800 billion in spending (United States Census Bureau, 2011), while also employing over 7 million individuals (Bureau of Labor Statistics, 2010). As a significant component, the industry's performance is critical to the success and well-being of the country's economy. Oglesby et al. (1989) divides construction performance into four categories: productivity, safety, timeliness, and quality. Often interrelated, these factors are the drivers of individual project performance, as well as the industry as a whole. In particular, construction productivity has been a focus of many academic studies, and improving productivity will be an ongoing research topic.

A construction project's stakeholders are concerned with productivity and adopt policies, practices, and procedures to improve productivity. However, a project's productivity ultimately hinges on workface practices. If the construction craft workers are not equipped with the necessary tools, information, materials, and equipment to effectively perform their tasks, the productivity of the project will be negatively affected. Many craft workers feel that information delivery, and further design or construction drawing management, is a significant factor to efficiently performing their job (Construction Industry Institute, 2006; Dai et al., 2009a; Dai et al., 2009b; Mourgues and Fischer, 2008; Rojas, 2008; and Schwartzkopf, 2004). Prior research found inefficiencies from drawing management exist due to errors in the drawing, availability of the drawings, slow management response to questions, legibility, and omission of necessary information on the documents (Construction Industry Institute, 2006; Dai et al., 2009a; and Dai et al., 2009b). Poor information delivery has the potential to create a ripple effect throughout the project. Mourgues and Fischer (2008) argue that communication of project information to the workface is ineffective and can negatively impact quality, safety, and productivity. Rojas (2008) and Schwartzkopf (2004) discuss inefficiencies from design drawings ultimately leading to increased rework on the project. Supervisors and foremen then become focused on correcting engineering errors and rework instead of planning future work and focusing on crew performance.

While drawing management and information delivery has been identified as a source of inefficient work, the standard practices and procedures have not changed. Craft workers are ultimately presented with the same standard set of two dimensional drawings that they have been for many years. With advances in three dimensional modeling and further three dimensional printing, there is an opportunity to improve the method of information delivery for stakeholders.

APPENDIX B – Study Design (Excerpt from Research Proposal)

PROPOSED RESEARCH STRATEGY

The primary objective of this research is to evaluate and determine the most effective medium for information processing by construction craft workers. The primary contribution to the overall body of knowledge is to scientifically examine the effect that different engineering information mediums have on an individual's cognitive ability to effectively and accurately interpret spatial information. Further, several secondary or supportive objectives will increase the value to the research findings and were detailed in Section 1.3. In order to accomplish the research objectives, comprehensive strategies have been developed for each objective. The strategies for each objective are detailed in the subsequent sections.

Understand the cognitive principles behind spatial information processing

This objective has been addressed through the previous literature review discussed throughout Chapter 2.

Identify the uses of the different information mediums available for construction craft workers

Similarly, this objective was addressed in Chapter 2 when evaluating the educational and instruction psychology literature.

Develop a standard model for evaluation

As a means to provide the dissertation committee an idea of 3D printers' capabilities and the general methodology of the study, the doctoral candidate has developed a set of 2D plans, a 3D interface, and a 3D physical model of a simple structural model (see Figures 3-1, 3-2, 3-3, 3-4, 3-5, and 3-6). The concept behind the study is to assess individual performance with each type of information delivery. To assist in that effort, the test subjects will be exposed to one type of media and be asked to assemble it using some simple plastic modeling systems. The subjects will be timed until completion and monitored for tendencies and incidents of "rework". The National Aeronautics and Space Administration Task Load Index (NASA-TLX) will also help to assess the subject's ease of use, difficulties, preferences, and ideas for improvement for the information media. As a subjective measure using a Likert scale, the NASA-TLX is subject to variance and individual differences between respondents. To correct for the differences, the subjects will be asked to complete the model using the different types of information delivery. Each format will have a similar model in scale, but with varying geometries. The change in responses will provide a normalized measure for how the individuals perceive their ability to work with the different mediums.

The doctoral candidate has also obtained several other building project models that can be used in the study. The models could be printed and used in the methodology presented within this proposal or a demonstration of the capabilities of 3D printers. A survey of the uses and potential of the model in construction could yield some insights to industry's perception of the output.

Develop and test assessment forms and a study for testing the effectiveness of the model

With regard to previous cognitive studies in spatial understanding, several assessment forms for subjects will be used. This will include timed and untimed elements to evaluate the subject's ability to manipulate and recreate spatial information using a 2D dimensional drawing, a 3D interface, and a 3D physical model. The subjects will be tested in their timeliness and accuracy in their responses per the National Aeronautics and Space Administration Raw Task Load Index (NASA-rTLX). Other measures that will be evaluated include spatial orientation ability, time to completion, a five-minute rating analysis, and a post-test questionnaire. Spatial orientation abilities are evaluated by using the spatial orientation aptitude test provided by the Educational Testing Services (ETS). Two dimensional spatial orientation is evaluated by the card rotations test as seen in Figure 2-13. Three dimensional spatial orientation is evaluated by the cube comparisons test as seen in Figure 2-14. Each test asks the subject's to answer a series of questions, and the ability is measured based off of the number of correct responses. Time to completion of the task for subjects will provide a look into the information delivery formats that lend to quicker task completion. The five-minute rating will yield percent of time spent on non-direct work activities, or activities resulting in rework. To conduct a five-minute rating, the candidate will prepare a time sheet broken down into subsets of time and then columns for notation of the activity classification. The classification categories are direct work, indirect work, rework, and delay due to rework. Direct work will be defined as any physical building of the model towards the final product. Indirect work will be defined as any activities performed towards the end result that is not physically building the model. This includes time getting familiar with the building elements, and manipulating and processing the information delivery format. Rework includes any disassembling or reassembling of a previously built portion of the model. Finally, delay due to rework includes time spent reprocessing the information delivery medium after rework occurs. Notes to the activity being performed during each segment can also be taken on the sheet. See section 3.5.2 for further discussion. Spatial orientation testing is discussed in section 3.4.2, while time to completion and five-minute rating is covered in section 3.5.2.

Reliable and validated outcome measures will also provide critical data for analysis. This is discussed further in Section 3.5.

Treatment groups, sample size, and variable definitions

For an effective ANOVA analysis, a sample size determination and treatment groups will have to be established for testing. The treatment groups for the test will be the 2D drawings, 3D interface, and 3D physical model. This allows for testing differences between the groups to determine which treatment group results in the lowest mental demand. To determine the sample size for each group, Equation 3-1 results in an estimate for sample size based off of the confidence level, estimated standard deviation, and desired difference from the true mean.

Equation 0-1

95% Confidence Level: $\sqrt{n} = \frac{1.96\sigma}{L}$, where n = sample size, σ = estimated standard deviation, and L = desired difference from the true mean (Rosner, 2006).

Estimating a standard deviation for this study is a difficult task, as there have been no similar studies to leverage. For example using the composite workload measure from the NASA-rTLX as the dependent variable, an estimated standard deviation of five (on a scale of 0-100) would prove to be reasonable. Subjective measures often result in less extreme values, so a standard deviation of five is conservative. The desired difference from the true mean would be acceptable at a level of two. This value provides a level of accuracy from the resulting ANOVA analysis. By using two, the ANOVA analysis will provide a sample mean within two of the true mean in each direction. Using the subjective NASA-rTLX composite score as the dependent variable, an error of two is reasonable. Using the equation with the mentioned values, the sample size for each treatment group must be at least 24 subjects.

Other dependent variables that will be investigated include time to completion, rework percentage and direct work percentage. These variables are defined in Table 3-1. Conducting the sample size calculation for the other two dependent variables, similar assumptions are used, resulting in the same sample size.

Subjects for the study are proposed to be civil engineering students at the University of Kentucky with varying years of experience and construction craft workers also with varying years of experience. The students will be obtained by the doctoral candidate or his doctoral advisor based off of the current teaching assignments. The doctoral candidate will be the main instructor for a class of approximately 25 students in the spring semester of 2012. The candidate can recruit students on their own will or perhaps with motivation from extra credit points depending on the perception of the students. The candidate also maintains strong industry contacts from his work experience with a regional construction company with several hundred employees. This company, and several others, have participated in several research projects with the University in the past and are active in events and meetings with the University's industry advisory board. Between the numerous contacts that the doctoral committee retains in the industry, there will be a great opportunity to obtain the participation of construction craft workers. The minimum sample size that will be targeted will be 24, with a mix of students and craft workers. An ideal figure would be 24 students and 24 craft workers that allows for further statistical analysis.

The proposed ANOVA model will include several variables as outlined and defined in Table 3-1. The model includes but is not limited to these variables, and several statistical outcomes could be found from the data.

Table 0-1. ANOVA model variable identification and definitions

Variable	**Description**
Composite Workload*	Measure of the total amount of workload required to complete the task. (0-100, from the NASA-rTLX composite score)
Mental Demand	How much mental and perceptual activity was required? Was the task easy or demanding, simple or complex, exacting or forgiving? (0-100, from the NASA-rTLX)
Physical Demand	How much physical activity was required? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious? (0-100, from the NASA-rTLX)
Temporal Demand	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic? (0-100, from the NASA-rTLX)
Operator Performance	How successful do you think you were in accomplishing the goals of the task set by the experimenter? How satisfied were you with your performance in accomplishing these goals? (0-100, from the NASA-rTLX)
Effort	How hard did you have to work (mentally and physically) to accomplish your level of performance? (0-100, from the NASA-rTLX)
Frustration	How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task? (0-100, from the NASA-rTLX)
Order of Completion	Order of delivery format task completion. Shows transfer of

	knowledge from one format to another.
2D Spatial Orientation Performance	Ability to mentally rotate and understand 2D information. (0-100%, given from the card rotations test)
3D Spatial Orientation Performance	Ability to mentally rotate and understand 3D information. (0-100%, given from the cube comparisons test)
Time to Completion*	Time to complete the task
Direct Work Percentage*	Percent of time spent on physically building of the model towards the final product (0-100%, given from the 5-minute rating)
Indirect Work Percentage	Percent of time spent towards the end result of the final product that is not physically building the model (i.e. manipulating the information delivery format, planning action, gaining familiarity with the model pieces) (0-100%, given from the 5-minute rating)
Rework Percentage*	Percent of time spent disassembling or reassembling of a previously built portion of the model (0-100%, given from the 5-minute rating)
Delay Due to Rework Percentage	Percent of time spent reprocessing the information delivery medium after rework occurs (0-100%, given from the 5-minute rating)
Occupation	Either student or craft worker (given from demographic sheet)
Years of Experience	Years of experience in industry requiring drawing interpretation (given from demographic sheet)
Age	Age of subject (given from demographic sheet)
Gender	Gender of subject (given from demographic sheet)

* Dependent variables

To gauge the performance of each information delivery platform, the study defines effective presentation as simple, quick, and easily interpretable (Emmitt and Gorse, 2003). Subsequently, the response (dependent) variables are the composite workload measure, time to completion, direct work percentage, and rework percentage. The composite workload measure will identify which treatment group requires the least amount of mental capacity to perform the task, essentially the simplest to mentally encode. The time to completion shows which information delivery medium lends itself to quickest interpretation and completion of the task. The direct work and rework percentages will identify which platform results in the most value-added versus waste activities. It also illustrates which medium may be the most user-friendly for correct interpretation of spatial information.

Proof of concept

As a means to provide the dissertation committee an idea of 3D printer's capabilities and the general methodology of the study, the doctoral candidate has developed a set of 2D plans, a 3D interface, and a 3D physical model of a simple structural model. Figures 3-1, 3-2, 3-3, and 3-4 show the simple model in a 2D format in plan, front, and right views and an isometric view of the 3D interface respectively. Figures 3-5 and 3-6 show the printed output of the model in an elevation view and isometric view respectively. The concept behind the study is to assess individual performance with each type of information delivery. To assist in that effort, the subjects will be exposed to one type of media and be asked to assemble it using plastic modeling elements. The subjects will be timed until completion and monitored for tendencies and incidents of "rework". In this study, rework is defined as any activities that are not effective towards building the desired model. This includes disassembling of any portions of the model, reassembling of a previously built portion of the model, and any delay due to rethinking or evaluating a previously built portion of the model. A post-test assessment form will also help to assess the subject's ease of use, difficulties, preferences, and ideas for improvement for the information media.

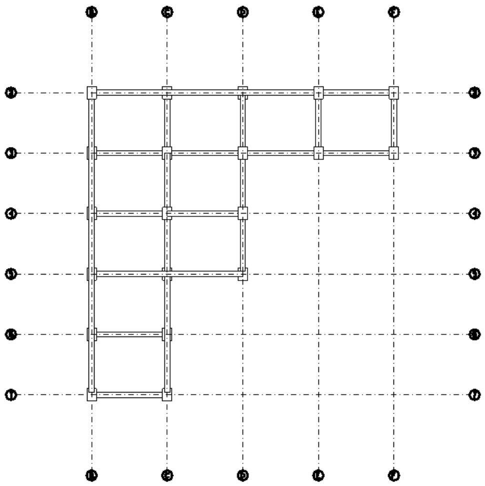


Figure 0.1. Plan view

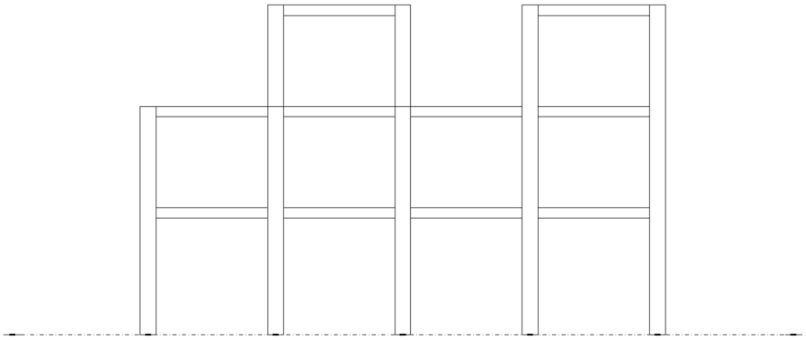


Figure 0.2. Front view

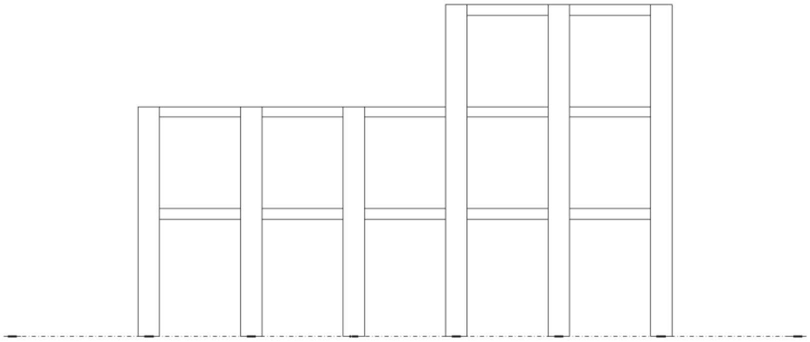


Figure 0.3. Right view

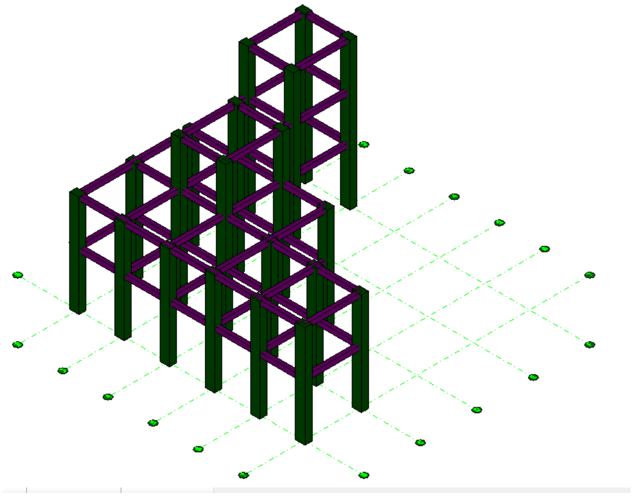


Figure 0.4. 3D isometric view of the 3D interface

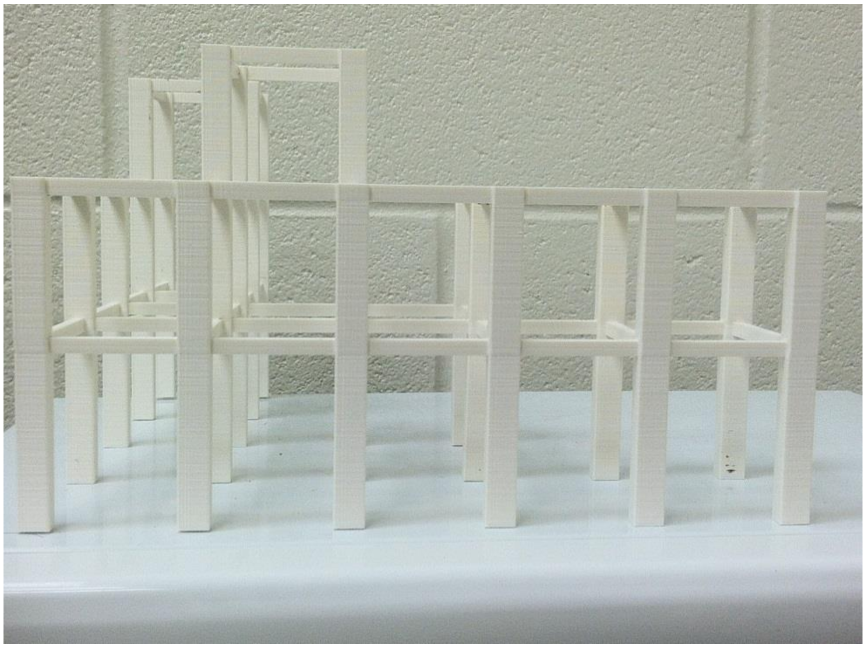


Figure 0.5. Elevation view of the physical model

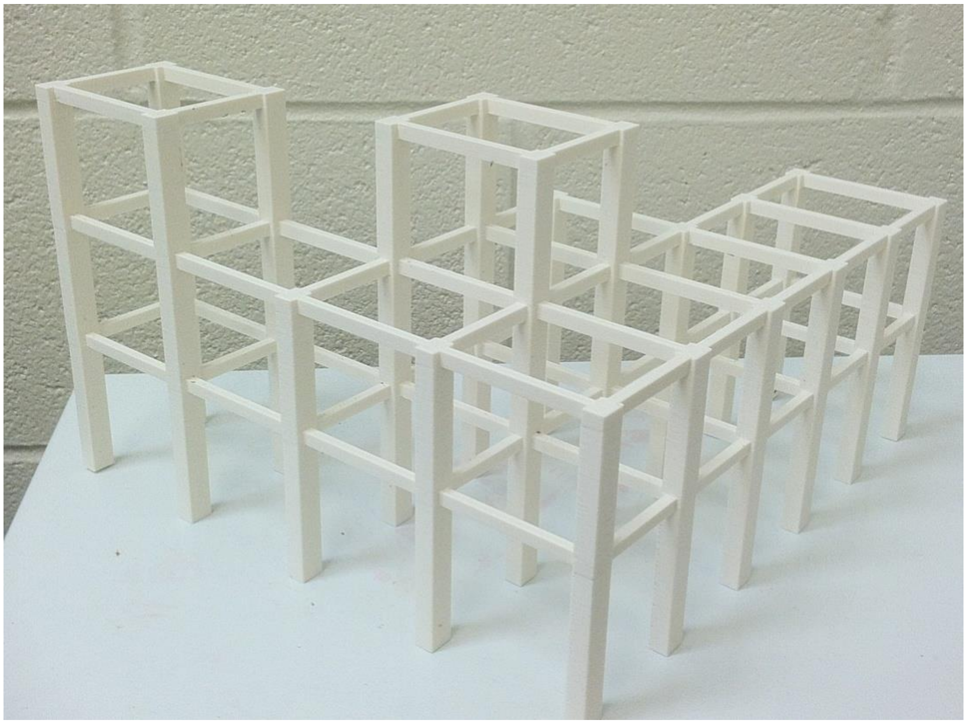


Figure 0.6. Isometric view of the physical model

Leveraging cognitive factors for spatial ability testing

Using an individual's spatial ability (discussed in Section 2.5.1 Cognitive Factors for Spatial Processing) and the proof of concept (Section 3.4.1) as guidance, the study will seek to test the major factors involved in spatial information processing. The major factors are visualization, spatial orientation, flexibility of closure, perceptual speed, and closure speed. Definitions for each factor as defined by Carroll (1993) can be found in Table 3-2.

Table 0-2. Major factors for spatial ability (Carroll, 1993)

Factor Name	General Definition
Visualization	Ability to perceive multiple patterns accurately and evaluate one with the others
Spatial Orientation	Ability to understand various orientations in which a pattern is presented
Flexibility of Closure	Manipulation of two configurations at the same time or in succession in a convoluted environment
Perceptual Speed	Speed in finding a given configuration within a system of distracting elements
Closure Speed	Ability to merge disconnected, vague, and visual elements into a logical whole

While these factors play important roles in an individual's spatial ability, the factor that will be studied is spatial orientation/relations. The tests for spatial orientation developed by the ETS and in Ekstrom et al. (1976) focus on an individual's ability to rotate and encode items in two and three dimensional space. This test has a direct correlation to the study of recreating a 3D model from the information delivery formats discussed (2D drawings, 3D interface, and 3D physical model). The findings will be incorporated into the analysis of performance on the NASA-rTLX. There should be a correlation between performance on the spatial orientation test and performance on the proposed task.

Visualization and spatial orientation are similar factors according to Ekstrom et al. (1976). However, they differ in that visualization requires that the overall figure be separated into components prior to manipulation. Spatial orientation requires the user to manipulate the entire figure at once. Spatial orientation is then the more applicable factor study for the whole model that was presented in Section 3.4.1.

Flexibility of closure, perceptual speed, and closure speed all require understanding and manipulation of objects in a convoluted, distracting, or disconnected environment. This dissertation focuses on the study of simple and clear models, which does not lend itself to properly evaluating the flexibility of closure, perceptual and closure speed cognitive factors. The study of these cognitive factors for future work is discussed in Section 3.9.

Evaluate and assess the findings of the research

There are several outcome measures that will be used to evaluate the performance of the subject's ability to use the models. Assessment forms and observation studies will be used as discussed in the following subsections. Such methodology is used in previous studies to evaluate the effectiveness of information presentation (Cockburn and McKenzie, 2002; Tharanathan et al., 2010).

Subjective measures

One of the most widely used standardized subjective measures of mental workload is the National Aeronautics and Space Administration Raw Task Load Index (NASA-rTLX). Carswell et al. (2005) describe the NASA-rTLX as "multidimensional measures that require respondents to make ratings. The individual scales may be used for diagnostic purposes, and a composite workload measure can be obtained by summarizing across scales." The examination rates responses in scales of mental demand, physical demand, temporal demand, effort, performance, and frustration. Table 3-3 outlines the index's rating scales and their definitions, which are the factors that are weighted in the final outcome measure. The scales are assigned a rating from zero to 100 with zero being the least taxing and 100 being the most taxing. The subscales are summed and averaged to identify an overall workload score from zero to 100.

The traditional version of the NASA-TLX also incorporates a pairwise comparison of the subscales to determine weights of the overall magnitude of the subscales. The raw version, used in this study and many others, eliminates the pairwise comparison and strictly uses the magnitude rating of the subscales. This makes the measurement simpler and does not affect the ultimate conclusions of the scale (Hart, 2006).

The advantages of a subjective measure are their widespread acceptance and use as well as the ability to easily administer and interpret the results. However, there are drawbacks to current subjective measures. The subject's must self-evaluate their performance and their cognitive capacity. When responses are obtained verbally, research has shown that subjects tend to respond from their working memory and not their mental workload. Working memory is the active portion of memory that is limited in capacity and retention (Carswell et al., 2005). Therefore, an immediate written self-assessment will provide a measure of mental workload. Response bias could also factor into the results if the subjects are stakeholders in the study. For instance, if conducting this study with a veteran journeyman electrician, he or she may be inclined to prefer the traditional drawing set that has been traditionally used.

Table 0-3. NASA-rTLX Rating Scale Definitions (Hart and Staveland, 1988)

Factor	Endpoints	Description
Mental Demand	Low/High	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, and searching)? Was the task easy or demanding, simple or complex, exacting or forgiving?
Physical Demand	Low/High	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
Temporal Demand	Low/High	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
Performance	Good/Poor	How successful do you think you were in accomplishing the goals of the task set by the experimenter? How satisfied were you with your performance in accomplishing these goals?
Effort	Low/High	How hard did you have to work (mentally and physically) to accomplish your level of performance?
Frustration Level	Low/High	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

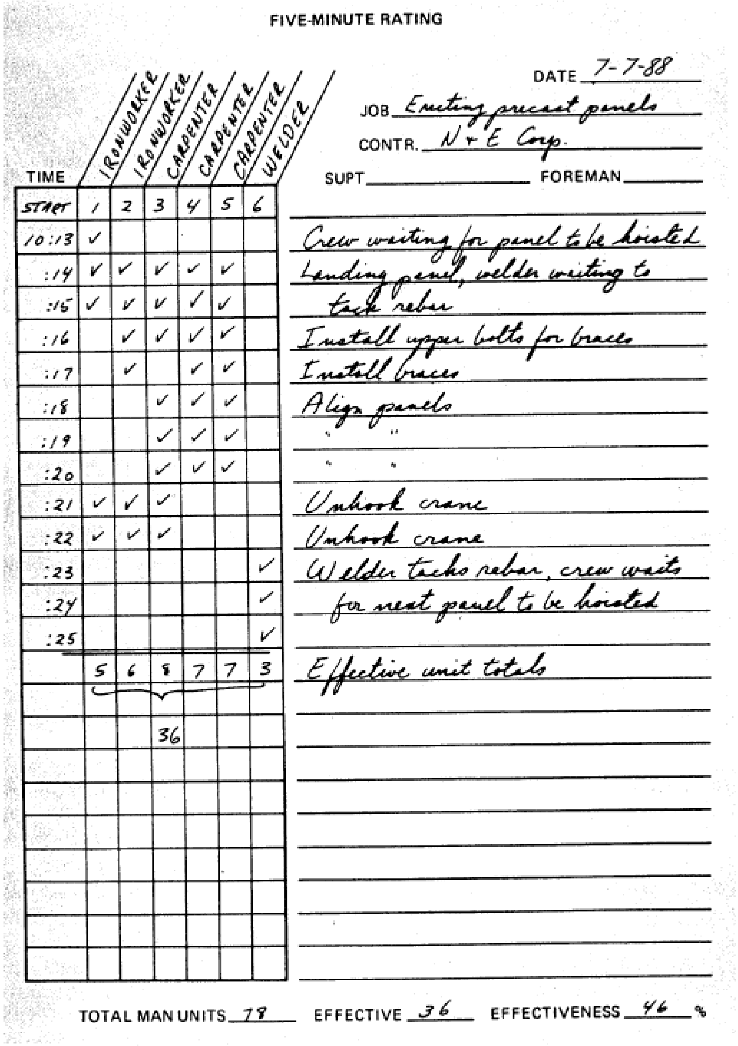
The raw NASA-rTLX asks respondents for their perception of the impact of the categories listed in Table 3-2. The data analysis presented in Hart and Staveland (1988) will determine which information delivery format requires the most mental workload to complete the task.

Another subjective measure will be from a post-test questionnaire. This questionnaire will have two main outcomes. The first will ask which information delivery format was preferred when completing the task and why. The second will ask the subject which information delivery format they would use to perform a series of tasks related to construction activities. The tasks will be biased towards a particular delivery format and will illustrate biased preferences for one format over another.

Objective measures

To support and provide further results, several objective measures will be taken during the administration of the study to gauge performance. Time to task completion, incidences and frequency of rework are the key objective measures that will be obtained. The subjects will be asked to start and stop a timer when they begin and finish the task. In addition, the order of delivery format task completion will be tracked. Subjects will be asked to complete the formats in random order, which will be noted. The resulting data will identify any transfer of knowledge from one format to another. To efficiently track the occurrence and frequency of rework, the candidate will conduct a five-minute rating analysis.

Five-minute rating analyses have been performed on many construction field projects to "create awareness on the part of management of delay in a job and indicate its order of magnitude, measure the effectiveness of a crew, and indicate where more thorough, detailed observations or planning could result in savings (Oglesby et al., 1989)." For this experiment, a five-minute rating will yield the percent of the task that was spent on non-effective work or rework. The percentage can be applied to the overall time to completion to give the amount of time spent on rework. The figures should yield effective work percentages of each information delivery format. To conduct a five-minute rating, the candidate will prepare a time sheet broken down into subsets of time and then columns for notation of the activity classification. The classification categories are direct work, indirect work, rework, and delay due to rework. Direct work will be defined as any physical building of the model towards the final product. Indirect work will be defined as any activities performed towards the end result that is not physically building the model. This includes time getting familiar with the building elements, and manipulating and processing the information delivery format. Rework includes any disassembling or reassembling of a previously built portion of the model. Finally, delay due to rework includes time spent reprocessing the information delivery medium after rework occurs. Notes to the activity being performed during each segment can also be taken on the sheet. A sample five-minute rating sheet from Oglesby et al. (1989) can be seen in Figure 3-7. To ease in the assessment of the five-minute rating, the subjects will be videotaped for the sole purpose of data collection for the five-minute rating. The candidate will submit proper documentation to the University of Kentucky's Office of Research Integrity (ORI), which is the University's in house Institutional Review Board (IRB), for prior approval.



FIVE-MINUTE RATING

DATE 7-7-88
JOB Erecting precast panels
CONTR. N + E Corp.
SUPT ______ FOREMAN ______

TIME	IRONWORKER	IRONWORKER	CARPENTER	CARPENTER	CARPENTER	WELDER	
START	1	2	3	4	5	6	
10:13	✓						Crew waiting for panel to be hoisted
:14	✓	✓	✓	✓	✓		Landing panel, welder waiting to
:15	✓	✓	✓	✓	✓		tack rebar
:16		✓	✓	✓	✓		Install upper bolts for braces
:17		✓		✓	✓		Install braces
:18			✓	✓	✓		Align panels
:19			✓	✓	✓		″ ″
:20			✓	✓	✓		″ ″
:21	✓	✓	✓				Unhook crane
:22	✓	✓	✓				Unhook crane
:23						✓	Welder tacks rebar, crew waits
:24						✓	for next panel to be hoisted
:25						✓	
	5	6	8	7	7	3	Effective unit totals
			36				

TOTAL MAN UNITS 78 EFFECTIVE 36 EFFECTIVENESS 46 %

Figure 0.7. Sample five-minute rating sheet from Oglesby et al. (1989)

Data Analysis

To evaluate the findings, an appropriate statistical analysis will be utilized. The individual outcomes of the subjective workload measure are a weighted workload for each of the tested factors (physical demand, mental demand, temporal demand, operator performance, effort, and frustration) and an overall workload for the information delivery medium. The objective measures will result in a time to completion, direct work percentage, indirect work percentage, rework percentage, and delay due to rework percentage. All of these figures, objective and subjective, can be combined into a single statistical model for analysis.

As the study investigates individual performance among three separate tests, one way pairwise and an overall analysis of variance (ANOVA) for the three treatment groups will be utilized. A fixed effects ANOVA model results in whether there is a difference in the means of the response variables between the treatment groups (Dielman, 2005). Pairwise ANOVA will give a comparison between each treatment group, while the overall ANOVA will yield the most effective treatment group with all groups considered.

For an effective ANOVA analysis, a sample size determination and treatment groups will have to be established for testing. The treatment groups for the test will be the 2D drawings, 3D interface, and 3D physical model. This allows for testing differences between the groups to determine which treatment group results in the lowest mental demand. The minimum sample size necessary for the ANOVA analysis is 24 as described in Section 3.4.1. The subjects will be civil engineering students at the University of Kentucky with varying years of experience and construction craft workers also with varying years of experience.

An effective information delivery medium is defined as simple, quick, and easily interpretable. To that end, the response variables for the study are composite workload from the NASA-rTLX, time to completion, direct work percentage, and rework percentage. For further definitions and descriptions, see Table 3-1. The composite workload measures the ease of understanding of the delivery method which provides a measure of simplicity for cognition. The time to completion variable provides the platform that lends to quickest completion of the task. Direct work and rework percentages measure the amount of time spent on productive work and repeated or wasteful work. These variables will identify which platform is easiest to interpret.

The proposed ANOVA model will include several variables as outlined and defined in Table 3-1. The model includes but is not limited to these variables, and several statistical outcomes could be found from the data (discussed further in Section 3.4.1).

APPENDIX C – Study Population (Excerpt from Research Proposal)

***Note: for this IRB filing, the investigator will be studying the students discussed. The same study will include construction craft workers, as discussed below, however, that will be a separate, subsequent IRB filing.**

Treatment groups, sample size, and variable definitions

For an effective ANOVA analysis, a sample size determination and treatment groups will have to be established for testing. The treatment groups for the test will be the 2D drawings, 3D interface, and 3D physical model. This allows for testing differences between the groups to determine which treatment group results in the lowest mental demand. To determine the sample size for each group, Equation Error! No text of specified style in document.**-1** results in an estimate for sample size based off of the confidence level, estimated standard deviation, and desired difference from the true mean.

Equation 0-2

95% Confidence Level: $\sqrt{n} = \frac{1.96\sigma}{L}$, where n = sample size, σ = estimated standard deviation, and L = desired difference from the true mean (Rosner, 2006).

Estimating a standard deviation for this study is a difficult task, as there have been no similar studies to leverage. For example using the composite workload measure from the NASA-rTLX as the dependent variable, an estimated standard deviation of five (on a scale of 0-100) would prove to be reasonable. Subjective measures often result in less extreme values, so a standard deviation of five is conservative. The desired difference from the true mean would be acceptable at a level of two. This value provides a level of accuracy from the resulting ANOVA analysis. By using two, the ANOVA analysis will provide a sample mean within two of the true mean in each direction. Using the subjective NASA-rTLX composite score as the dependent variable, an error of two is reasonable. Using the equation with the mentioned values, the sample size for each treatment group must be at least 24 subjects.

Other dependent variables that will be investigated include time to completion, rework percentage and direct work percentage. These variables are defined in Table Error! No text of specified style in document.**-1**. Conducting the sample size calculation for the other two dependent variables, similar assumptions are used, resulting in the same sample size.

Subjects for the study are proposed to be civil engineering students at the University of Kentucky with varying years of experience and construction craft workers also with varying years of experience. The students will be obtained by the doctoral candidate or his doctoral advisor based off of recruitment through the display of fliers. The candidate also maintains strong industry contacts from his work experience with a regional construction company with several hundred employees. This company, and several others, have participated in several research projects with the University in the past and are active in events and meetings with the University's industry advisory board. Between the numerous contacts that the doctoral committee retains in the industry, there will be a great opportunity to obtain the participation of construction craft workers. The minimum sample size that will be targeted will be 24, with a mix of students and craft workers. An ideal figure would be 24 students and 24 craft workers that allows for further statistical analysis.

The proposed ANOVA model will include several variables as outlined and defined in Table Error! No text of specified style in document.**-1**. The model includes but is not limited to these variables, and several statistical outcomes could be found from the data.

Table 0-4. ANOVA model variable identification and definitions

Variable	**Description**
Composite Workload*	Measure of the total amount of workload required to complete the task. (0-100, from the NASA-rTLX composite score)
Mental Demand	How much mental and perceptual activity was required? Was the task easy or demanding, simple or complex, exacting or forgiving? (0-100, from the NASA-rTLX)
Physical Demand	How much physical activity was required? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious? (0-100, from the NASA-rTLX)
Temporal Demand	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic? (0-100, from the NASA-rTLX)
Operator Performance	How successful do you think you were in accomplishing the goals of the task set by the experimenter? How satisfied were you with your performance in accomplishing these goals? (0-100, from the NASA-rTLX)
Effort	How hard did you have to work (mentally and physically) to accomplish your level of performance? (0-100, from the NASA-rTLX)
Frustration	How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task? (0-100, from the NASA-rTLX)

Order of Completion	Order of delivery format task completion. Shows transfer of knowledge from one format to another.
2D Spatial Orientation Performance	Ability to mentally rotate and understand 2D information. (0-100%, given from the card rotations test)
3D Spatial Orientation Performance	Ability to mentally rotate and understand 3D information. (0-100%, given from the cube comparisons test)
Time to Completion*	Time to complete the task
Direct Work Percentage*	Percent of time spent on physically building of the model towards the final product (0-100%, given from the 5-minute rating)
Indirect Work Percentage	Percent of time spent towards the end result of the final product that is not physically building the model (i.e. manipulating the information delivery format, planning action, gaining familiarity with the model pieces) (0-100%, given from the 5-minute rating)
Rework Percentage*	Percent of time spent disassembling or reassembling of a previously built portion of the model (0-100%, given from the 5-minute rating)
Delay Due to Rework Percentage	Percent of time spent reprocessing the information delivery medium after rework occurs (0-100%, given from the 5-minute rating)
Occupation	Either student or craft worker (given from demographic sheet)
Years of Experience	Years of experience in industry requiring drawing interpretation (given from demographic sheet)
Age	Age of subject (given from demographic sheet)
Gender	Gender of subject (given from demographic sheet)

* Dependent variables

To gauge the performance of each information delivery platform, the study defines effective presentation as simple, quick, and easily interpretable (Emmitt and Gorse, 2003). Subsequently, the response (dependent) variables are the composite workload measure, time to completion, direct work percentage, and rework percentage. The composite workload measure will identify which treatment group requires the least amount of mental capacity to perform the task, essentially the simplest to mentally encode. The time to completion shows which information delivery medium lends itself to quickest interpretation and completion of the task. The direct work and rework percentages will identify which platform results in the most value-added versus waste activities. It also illustrates which medium may be the most user-friendly for correct interpretation of spatial information.

UK
UNIVERSITY OF
KENTUCKY

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Lexington, KY 40506-0057
859 257-9428
fax 859 257-8995
www.research.uky.edu/ori/

Initial Review

Approval Ends
May 9, 2013

IRB Number
12-0303-P4S

TO:
Gabriel Biratu Dadi
Civil Engineering
151D Oliver H. Raymond Building
0281
PI phone #: (502) 314-8798

FROM:
Chairperson/Vice Chairperson
Non-medical Institutional Review Board (IRB)

SUBJECT: Approval of Protocol Number 12-0303-P4S

DATE: May 14, 2012

On May 10, 2012, the Non-medical Institutional Review Board approved your protocol entitled:

Applying Cognitive Principles to the Delivery of Engineering Information by Different Mediums

Approval is effective from May 10, 2012 until May 9, 2013 and extends to any consent/assent form, cover letter, and/or phone script. If applicable, attached is the IRB approved consent/assent document(s) to be used when enrolling subjects. **[Note, subjects can only be enrolled using consent/assent forms which have a valid "IRB Approval" stamp unless special waiver has been obtained from the IRB.]** Prior to the end of this period, you will be sent a Continuation Review Report Form which must be completed and returned to the Office of Research Integrity so that the protocol can be reviewed and approved for the next period.

In implementing the research activities, you are responsible for complying with IRB decisions, conditions and requirements. The research procedures should be implemented as approved in the IRB protocol. It is the principal investigators responsibility to ensure any changes planned for the research are submitted for review and approval by the IRB prior to implementation. Protocol changes made without prior IRB approval to eliminate apparent hazards to the subject(s) should be reported in writing immediately to the IRB. Furthermore, discontinuing a study or completion of a study is considered a change in the protocol's status and therefore the IRB should be promptly notified in writing.

For information describing investigator responsibilities after obtaining IRB approval, download and read the document "PI Guidance to Responsibilities, Qualifications, Records and Documentation of Human Subjects Research" from the Office of Research Integrity's Guidance and Policy Documents web page [http://www.research.uky.edu/ori/human/guidance.htm#PIresp]. Additional information regarding IRB review, federal regulations, and institutional policies may be found through ORI's web site [http://www.research.uky.edu/ori]. If you have questions, need additional information, or would like a paper copy of the above mentioned document, contact the Office of Research Integrity at (859) 257-9428.

N. Van Tubergen Ph.D./ah
Chairperson/Vice Chairperson

IRB Approval
12-0303
THIS FORM VALID
5/10/12 – 5/9/13

Consent to Participate in a Research Study

APPLYING COGNITIVE PRINCIPLES TO THE DELIVERY OF ENGINEERING INFORMATION BY DIFFERENT MEDIUMS

WHY ARE YOU BEING INVITED TO TAKE PART IN THIS RESEARCH?

You are being invited to take part in a research study about delivery of engineering information by different mediums and their cognitive effects. You are being invited to take part in this research study because of your expertise in working with and understanding engineering related spatial information. If you volunteer to take part in this study, you will be one of about fifty people to do so.

WHO IS DOING THE STUDY?

The person in charge of this study is Gabriel B. Dadi, hereby principal investigator or PI, a doctoral student of the University Of Kentucky's Department Of Civil Engineering. He is being guided in this research by Dr. Paul M. Goodrum. There may be other people on the research team assisting at different times during the study.

WHAT IS THE PURPOSE OF THIS STUDY?

By doing this study, we hope to learn the cognitive loading of different information mediums and perceptions and opinions relating to the formats. This will help designers and engineers better present their information for the end reader, the construction worker.

ARE THERE REASONS WHY YOU SHOULD NOT TAKE PART IN THIS STUDY?

If you are not at least 18 years of age, you should not participate.

WHERE IS THE STUDY GOING TO TAKE PLACE AND HOW LONG WILL IT LAST?

The research will take place in this room and will be completed in one session. The visit will take about two hours.

WHAT WILL YOU BE ASKED TO DO?

First, you will be asked to complete a standard demographic questionnaire. After this form is completed, you will be asked to complete two separate cognitive studies of spatial rotation ability. The first test is the Card Rotations test that will ask you to select a rotated version of an image that is identical to the initial image. The second test is the Cube Comparisons test that presents two six sided cubes. Your goal will be to select whether the cubes can be the same or are they different based off of a rotated presentation. Each of these spatial rotation tests have a time limit of three minutes.

Next you will be presented with a simple structure in a two dimensional drawing set, three dimensional interface, or a three dimensional physical model. You will have a set of scaled building elements in front of you and then will be asked to recreate the structure using the building elements. During this exercise, you will be timed and videotaped.

At the conclusion of this exercise, you will be asked to complete a subjective rating scale of the demands that were encountered during the completion of the task. There will also be a follow up questionnaire concerning preferences in dealing with the various information delivery formats.

WHAT ARE THE POSSIBLE RISKS AND DISCOMFORTS?

To the best of our knowledge, the things you will be doing have no more risk of harm than you would experience in everyday life.

WILL YOU BENEFIT FROM TAKING PART IN THIS STUDY?

There is no guarantee that you will get any benefit from taking part in this study. Your willingness to take part, however, may, in the future, help society as a whole better understand this research topic.

DO YOU HAVE TO TAKE PART IN THE STUDY?

If you decide to take part in the study, it should be because you really want to volunteer. You will not lose any benefits or rights you would normally have if you choose not to volunteer. You can stop at any time during the study and still keep the benefits and rights you had before volunteering. As a student, if you decide not to take part in this study, your choice will have no effect on you academic status or grade in the class.

IF YOU DON'T WANT TO TAKE PART IN THE STUDY, ARE THERE OTHER CHOICES?

If you do not want to be in the study, there are no other choices except not to take part in the study.

WHAT WILL IT COST YOU TO PARTICIPATE?

There are no costs associated with taking part in the study.

WILL YOU RECEIVE ANY REWARDS FOR TAKING PART IN THIS STUDY?

If you decide to participate in the study, your name will be entered into a raffle for a $50 gift card from Lowe's. After the drawing occurs, the PI will contact the winner of the gift card using the contact information provided on the demographic questionnaire.

WHO WILL SEE THE INFORMATION THAT YOU GIVE?

We will make every effort to keep private all research records that identify you to the extent allowed by law.

Your information will be combined with information from other people taking part in the study. When we write about the study to share it with other researchers, we will write about the combined information we have gathered. You will not be personally identified in these written materials. We may publish the results of this study; however, we will keep your name and other identifying information private.

We will make every effort to prevent anyone who is not on the research team from knowing that you gave us information, or what that information is. A random identifier will be assigned to your responses to the study as well as the video file from the completion of the task. The data (paper and computer) will be stored under the random identifier that is assigned and safely stored in the PI's locked computer and desk office. Once the video file has been transferred to the computer, any remnants on the video camera will be deleted.

We will keep private all research records that identify you to the extent allowed by law. However, there are some circumstances in which we may have to show your information to other people. For example, the law may require us to show your information to a court. Also, we may be required to show information which identifies you to people who need to be sure we have done the research correctly; these would be people from such organizations as the University of Kentucky

CAN YOUR TAKING PART IN THE STUDY END EARLY?

If you decide to take part in the study you still have the right to decide at any time that you no longer want to continue. You will not be treated differently if you decide to stop taking part in the study.

The individuals conducting the study may need to withdraw you from the study. This may occur if you are not able to follow the directions they give you, if they find that your being in the study is more risk than benefit to you, or if the agency funding the study decides to stop the study early for a variety of scientific reasons.

WHAT IF YOU HAVE QUESTIONS, SUGGESTIONS, CONCERNS, OR COMPLAINTS?

Before you decide whether to accept this invitation to take part in the study, please ask any questions that might come to mind now. Later, if you have questions, suggestions, concerns, or complaints about the study, you can contact the investigator, Gabriel B. Dadi at gabe.dadi@uky.edu. If you have any questions about your rights as a volunteer in this research, contact the staff in the Office of Research Integrity at the University of Kentucky at 859-257-9428 or toll free at 1-866-400-9428. We will give you a signed copy of this consent form to take with you.

______________________________________ __________
Signature of person agreeing to take part in the study Date

____
Printed name of person agreeing to take part in the study

______________________________________ __________
Name of authorized person obtaining informed consent Date

IRB Approval
12-0303
THIS FORM VALID
5/10/12 - 5/9/13

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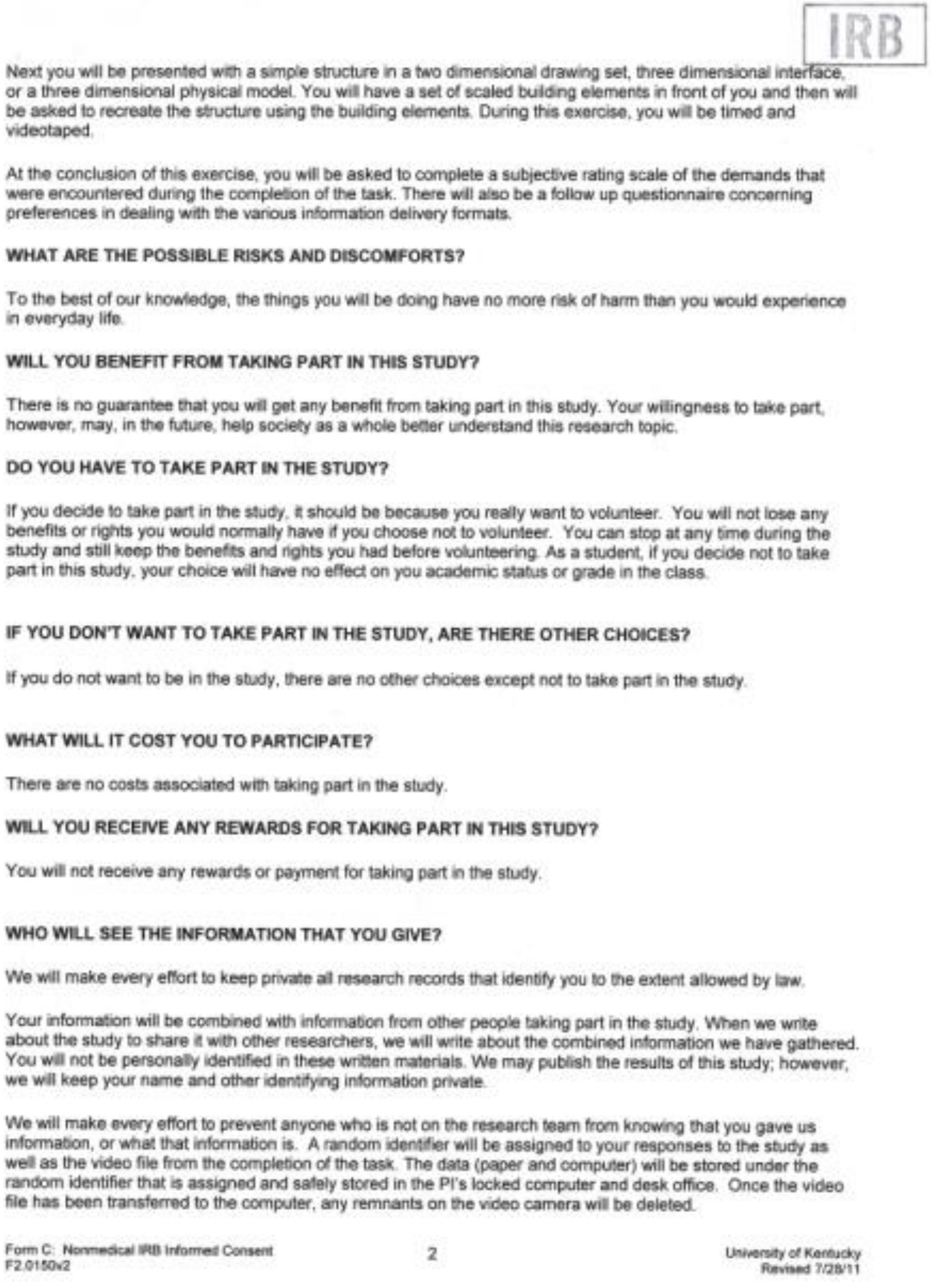
WHERE IS THE STUDY GOING TO TAKE PLACE AND HOW LONG WILL IT LAST?

The research procedures will be conducted at the Oliver H. Raymond Building on the campus of the University of Kentucky. You will need to come to Room C120 to complete the study, and it will be completed in one session. The visit will take about two hours.

WHAT WILL YOU BE ASKED TO DO?

First, you will be asked to complete a standard demographic questionnaire. After this form is completed, you will be asked to complete two separate cognitive studies of spatial rotation ability. The first test is the Card Rotations test that will ask you to select a rotated version of an image that is identical to the initial image. The second test is the Cube Comparisons test that presents two six sided cubes. Your goal will be to select whether the cubes can be the same or are they different based off of a rotated presentation. Each of these spatial rotation tests have a time limit of three minutes.



IRB

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WILL YOU RECEIVE ANY REWARDS FOR TAKING PART IN THIS STUDY?

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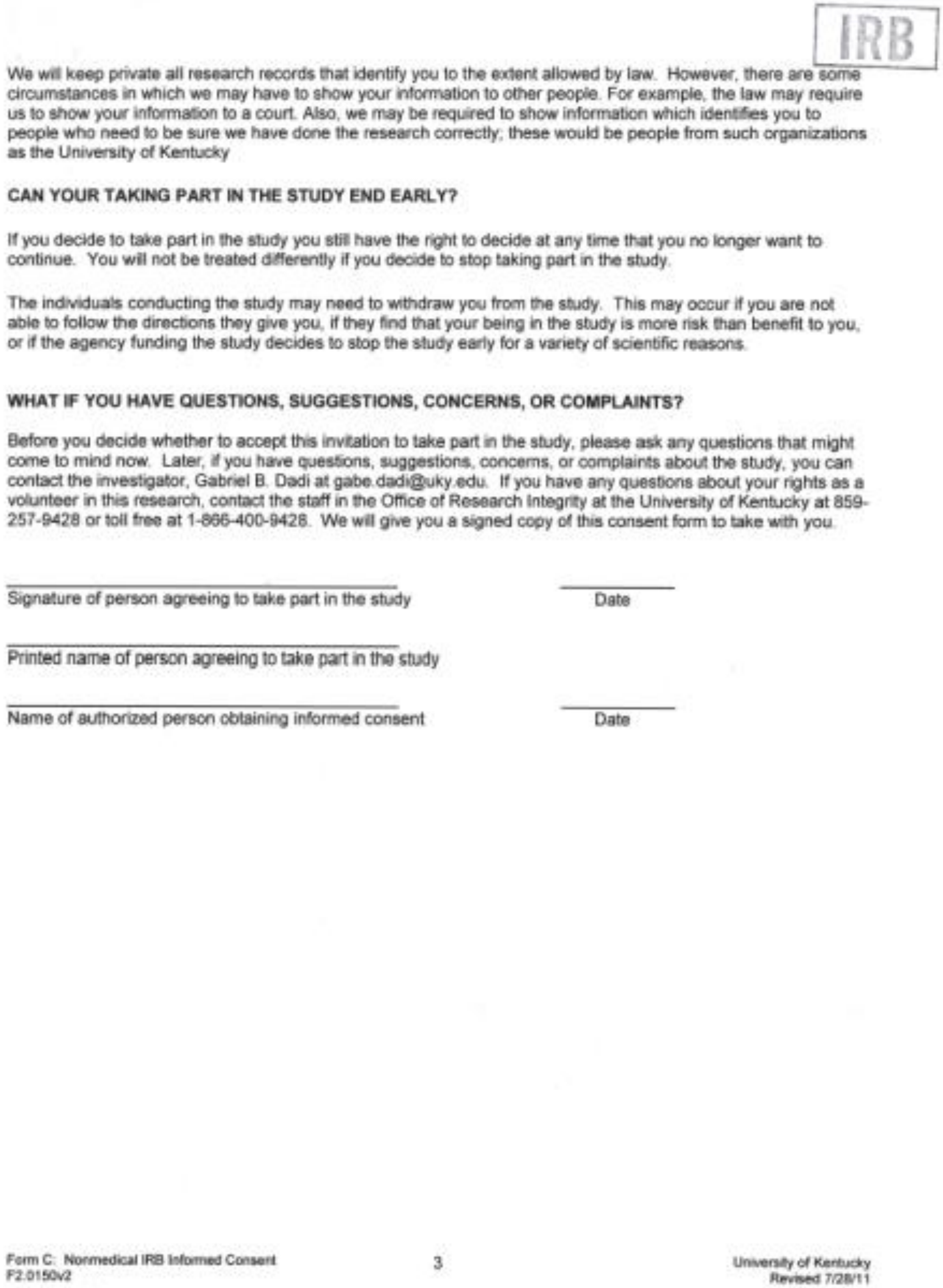
Your information will be combined with information from other people taking part in the study. When we write about the study to share it with other researchers, we will write about the combined information we have gathered. You will not be personally identified in these written materials. We may publish the results of this study; however, we will keep your name and other identifying information private.

We will make every effort to prevent anyone who is not on the research team from knowing that you gave us information, or what that information is. A random identifier will be assigned to your responses to the study as well as the video file from the completion of the task. The data (paper and computer) will be stored under the random identifier that is assigned and safely stored in the PI's locked computer and desk office. Once the video file has been transferred to the computer, any remnants on the video camera will be deleted.



IRB

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____________________________________ __________
Signature of person agreeing to take part in the study Date

____
Printed name of person agreeing to take part in the study

____________________________________ __________
Name of authorized person obtaining informed consent Date

Appendix H: SPSS ANOVA Output, All Subjects

Case Processing Summary

	Cases					
	Included		Excluded		Total	
	N	Percent	N	Percent	N	Percent
Age * Model	89	100.0%	0	0.0%	89	100.0%
Gender * Model	89	100.0%	0	0.0%	89	100.0%
Exp * Model	89	100.0%	0	0.0%	89	100.0%
Ref * Model	89	100.0%	0	0.0%	89	100.0%
CHrs * Model	89	100.0%	0	0.0%	89	100.0%
CAD * Model	89	100.0%	0	0.0%	89	100.0%
Time * Model	89	100.0%	0	0.0%	89	100.0%
Seq1 * Model	89	100.0%	0	0.0%	89	100.0%
Seq2 * Model	89	100.0%	0	0.0%	89	100.0%
Seq3 * Model	89	100.0%	0	0.0%	89	100.0%
Seq4 * Model	89	100.0%	0	0.0%	89	100.0%
Seq5 * Model	89	100.0%	0	0.0%	89	100.0%
Comp * Model	89	100.0%	0	0.0%	89	100.0%
MD * Model	89	100.0%	0	0.0%	89	100.0%
PD * Model	89	100.0%	0	0.0%	89	100.0%
TD * Model	89	100.0%	0	0.0%	89	100.0%
OP * Model	89	100.0%	0	0.0%	89	100.0%
EF * Model	89	100.0%	0	0.0%	89	100.0%
FR * Model	89	100.0%	0	0.0%	89	100.0%
CR * Model	89	100.0%	0	0.0%	89	100.0%
CC * Model	89	100.0%	0	0.0%	89	100.0%
DW * Model	89	100.0%	0	0.0%	89	100.0%
IW * Model	89	100.0%	0	0.0%	89	100.0%
RW * Model	89	100.0%	0	0.0%	89	100.0%
DRW * Model	89	100.0%	0	0.0%	89	100.0%
TwoDPIF * Model	89	100.0%	0	0.0%	89	100.0%
ThrDPIF * Model	89	100.0%	0	0.0%	89	100.0%
SES2D * Model	89	100.0%	0	0.0%	89	100.0%
SES3D * Model	89	100.0%	0	0.0%	89	100.0%
CSP2D * Model	89	100.0%	0	0.0%	89	100.0%
CSP3D * Model	89	100.0%	0	0.0%	89	100.0%
MEP2D * Model	89	100.0%	0	0.0%	89	100.0%
MEP3D * Model	89	100.0%	0	0.0%	89	100.0%
CFQ2D * Model	89	100.0%	0	0.0%	89	100.0%

CFQ3D * Model	89	100.0%	0	0.0%	89	100.0%
MC * Model	89	100.0%	0	0.0%	89	100.0%

Report

	Model											
	0			1			2			Total		
	Mean	N	Std. Deviation	Mean	N	Std. Deviation	Mean	N	Std. Deviation	Mean	N	Std. Deviation
Age	39.07	30	11.495	39.07	30	11.495	38.45	29	11.179	38.87	89	11.267
Gender	.10	30	.305	.10	30	.305	.10	29	.310	.10	89	.303
Exp	14.2807	30	11.54223	14.2807	30	11.54223	13.7386	29	11.35129	14.1040	89	11.35208
Ref	7.27	30	2.504	7.27	30	2.504	7.21	29	2.527	7.25	89	2.483
CHrs	39.53	30	63.146	39.53	30	63.146	40.90	29	63.812	39.98	89	62.643
CAD	.43	30	.504	.43	30	.504	.45	29	.506	.44	89	.499
Time	10.4417	30	2.62064	11.4977	30	3.88342	10.0986	29	4.00374	10.6858	89	3.56261
Seq1	.17	30	.379	.17	30	.379	.17	29	.384	.17	89	.376
Seq2	.17	30	.379	.17	30	.379	.17	29	.384	.17	89	.376
Seq3	.17	30	.379	.17	30	.379	.17	29	.384	.17	89	.376
Seq4	.17	30	.379	.17	30	.379	.14	29	.351	.16	89	.366
Seq5	.17	30	.379	.17	30	.379	.17	29	.384	.17	89	.376
Comp	33.8053	30	13.81395	34.4160	30	17.27720	30.4669	29	16.52115	32.9234	89	15.84664
MD	40.00	30	21.091	40.17	30	23.359	33.28	29	22.885	37.87	89	22.435
PD	29.50	30	19.447	29.17	30	19.302	27.76	29	20.159	28.82	89	19.424
TD	46.33	30	25.049	43.33	30	24.542	41.03	29	24.363	43.60	89	24.472
OP	22.33	30	16.281	25.00	30	19.343	20.86	29	20.662	22.75	89	18.693
EF	40.83	30	21.699	41.33	30	26.061	38.79	29	25.272	40.34	89	24.154
FR	23.83	30	19.857	27.50	30	20.834	23.79	29	21.450	25.06	89	20.553
CR	59.00	30	24.126	59.00	30	24.126	59.00	30	24.126	59.00	30	24.126
CC	32.30	30	23.334	32.30	30	23.334	32.30	30	23.334	32.30	30	23.334

DW	75.1250	30	8.88708	67.7860	30	17.17034	88.2231	29	10.09282	76.9191	89	15.07445
IW	21.4890	30	7.83542	25.6473	30	11.38560	8.0224	29	4.91821	18.5027	89	11.28213
RW	3.2193	30	5.30960	5.4313	30	8.64314	3.6921	29	8.06643	4.1190	89	7.45219
DRW	.1667	30	.91287	1.0727	30	2.17617	.0617	29	.33239	.4379	89	1.44204
TwoDPIF	.43	30	.504	.43	30	.504	.45	29	.506	.44	89	.499
ThrDPIF	.17	30	.379	.17	30	.379	.17	29	.384	.17	89	.376
SES2D	.17	30	.379	.17	30	.379	.17	29	.384	.17	89	.376
SES3D	.57	30	.504	.57	30	.504	.55	29	.506	.56	89	.499
CSP2D	.60	30	.498	.60	30	.498	.62	29	.494	.61	89	.491
CSP3D	.40	30	.498	.40	30	.498	.38	29	.494	.39	89	.491
MEP2D	.13	30	.346	.13	30	.346	.14	29	.351	.13	89	.343
MEP3D	.77	30	.430	.77	30	.430	.76	29	.435	.76	89	.427
CFQ2D	.43	30	.504	.43	30	.504	.45	29	.506	.44	89	.499
CFQ3D	.57	30	.504	.57	30	.504	.55	29	.506	.56	89	.499
MC	.27	30	.450	.27	30	.450	.28	29	.455	.27	89	.446

ANOVA Table

			Sum of Squares	df	Mean Square	F	Sig.
Age * Model	Between Groups	(Combined)	7.476	2	3.738	.029	.972
	Within Groups		11162.906	86	129.801		
	Total		11170.382	88			
Gender * Model	Between Groups	(Combined)	.000	2	.000	.001	.999
	Within Groups		8.090	86	.094		
	Total		8.090	88			
Exp * Model	Between Groups	(Combined)	5.744	2	2.872	.022	.978
	Within Groups		11334.787	86	131.800		
	Total		11340.531	88			
Ref * Model	Between Groups	(Combined)	.070	2	.035	.006	.994
	Within Groups		542.492	86	6.308		
	Total		542.562	88			
CHrs * Model	Between Groups	(Combined)	36.332	2	18.166	.005	.995
	Within Groups		345283.623	86	4014.926		
	Total		345319.955	88			
CAD * Model	Between Groups	(Combined)	.004	2	.002	.009	.991
	Within Groups		21.906	86	.255		
	Total		21.910	88			
Time * Model	Between Groups	(Combined)	31.560	2	15.780	1.250	.292
	Within Groups		1085.350	86	12.620		
	Total		1116.911	88			
Seq1 * Model	Between Groups	(Combined)	.001	2	.000	.002	.998
	Within Groups		12.471	86	.145		
	Total		12.472	88			

Seq2 * Model	Between Groups	(Combined)	.001	2	.000	.002	.998
	Within Groups		12.471	86	.145		
	Total		12.472	88			
Seq3 * Model	Between Groups	(Combined)	.001	2	.000	.002	.998
	Within Groups		12.471	86	.145		
	Total		12.472	88			
Seq4 * Model	Between Groups	(Combined)	.016	2	.008	.059	.943
	Within Groups		11.782	86	.137		
	Total		11.798	88			
Seq5 * Model	Between Groups	(Combined)	.001	2	.000	.002	.998
	Within Groups		12.471	86	.145		
	Total		12.472	88			
Comp * Model	Between Groups	(Combined)	265.168	2	132.584	.522	.595
	Within Groups		21833.031	86	253.872		
	Total		22098.199	88			
MD * Model	Between Groups	(Combined)	906.422	2	453.211	.898	.411
	Within Groups		43387.960	86	504.511		
	Total		44294.382	88			
PD * Model	Between Groups	(Combined)	50.147	2	25.073	.065	.937
	Within Groups		33150.977	86	385.476		
	Total		33201.124	88			
TD * Model	Between Groups	(Combined)	417.139	2	208.570	.343	.711
	Within Groups		52282.299	86	607.934		
	Total		52699.438	88			
OP * Model	Between Groups	(Combined)	260.447	2	130.223	.367	.694
	Within Groups		30490.115	86	354.536		
	Total		30750.562	88			

EF * Model	Between Groups	(Combined)	106.296	2	53.148	.089	.915
	Within Groups		51233.592	86	595.739		
	Total		51339.888	88			
FR * Model	Between Groups	(Combined)	270.294	2	135.147	.315	.731
	Within Groups		36904.425	86	429.121		
	Total		37174.719	88			
CR * Model	Between Groups	(Combined)	1.013	2	.506	.000	1.000
	Within Groups		129594.538	86	1506.913		
	Total		129595.551	88			
CC * Model	Between Groups	(Combined)	.153	2	.077	.001	.999
	Within Groups		8349.285	86	97.085		
	Total		8349.438	88			
DW * Model	Between Groups	(Combined)	6304.604	2	3152.302	19.799	.000
	Within Groups		13692.444	86	159.214		
	Total		19997.048	88			
IW * Model	Between Groups	(Combined)	4984.169	2	2492.084	34.473	.000
	Within Groups		6217.031	86	72.291		
	Total		11201.200	88			
RW * Model	Between Groups	(Combined)	81.234	2	40.617	.727	.486
	Within Groups		4805.863	86	55.882		
	Total		4887.097	88			
DRW * Model	Between Groups	(Combined)	18.399	2	9.199	4.807	.010
	Within Groups		164.596	86	1.914		
	Total		182.994	88			
TwoDPIF * Model	Between Groups	(Combined)	.004	2	.002	.009	.991
	Within Groups		21.906	86	.255		
	Total		21.910	88			

ThrDPIF * Model	Between Groups	(Combined)	.001	2	.000	.002	.998
	Within Groups		12.471	86	.145		
	Total		12.472	88			
SES2D * Model	Between Groups	(Combined)	.001	2	.000	.002	.998
	Within Groups		12.471	86	.145		
	Total		12.472	88			
SES3D * Model	Between Groups	(Combined)	.004	2	.002	.009	.991
	Within Groups		21.906	86	.255		
	Total		21.910	88			
CSP2D * Model	Between Groups	(Combined)	.008	2	.004	.017	.983
	Within Groups		21.228	86	.247		
	Total		21.236	88			
CSP3D * Model	Between Groups	(Combined)	.008	2	.004	.017	.983
	Within Groups		21.228	86	.247		
	Total		21.236	88			
MEP2D * Model	Between Groups	(Combined)	.000	2	.000	.002	.998
	Within Groups		10.382	86	.121		
	Total		10.382	88			
MEP3D * Model	Between Groups	(Combined)	.001	2	.001	.003	.997
	Within Groups		16.044	86	.187		
	Total		16.045	88			
CFQ2D * Model	Between Groups	(Combined)	.004	2	.002	.009	.991
	Within Groups		21.906	86	.255		
	Total		21.910	88			
CFQ3D * Model	Between Groups	(Combined)	.004	2	.002	.009	.991
	Within Groups		21.906	86	.255		
	Total		21.910	88			

MC * Model	Between Groups	(Combined)	.002	2	.001	.004	.996
	Within Groups		17.526	86	.204		
	Total		17.528	88			

Measures of Association

	Eta	Eta Squared
Age * Model	.026	.001
Gender * Model	.005	.000
Exp * Model	.023	.001
Ref * Model	.011	.000
CHrs * Model	.010	.000
CAD * Model	.014	.000
Time * Model	.168	.028
Seq1 * Model	.007	.000
Seq2 * Model	.007	.000
Seq3 * Model	.007	.000
Seq4 * Model	.037	.001
Seq5 * Model	.007	.000
Comp * Model	.110	.012
MD * Model	.143	.020
PD * Model	.039	.002
TD * Model	.089	.008
OP * Model	.092	.008
EF * Model	.046	.002
FR * Model	.085	.007
CR * Model	.003	.000
CC * Model	.004	.000
DW * Model	.561	.315
IW * Model	.667	.445
RW * Model	.129	.017
DRW * Model	.317	.101
TwoDPIF * Model	.014	.000
ThrDPIF * Model	.007	.000
SES2D * Model	.007	.000
SES3D * Model	.014	.000
CSP2D * Model	.020	.000
CSP3D * Model	.020	.000
MEP2D * Model	.006	.000
MEP3D * Model	.009	.000
CFQ2D * Model	.014	.000
CFQ3D * Model	.014	.000
MC * Model	.010	.000

Appendix I: SPSS ANOVA Output, Practitioners Only

Case Processing Summary

	Cases					
	Included		Excluded		Total	
	N	Percent	N	Percent	N	Percent
Age * Model	77	100.0%	0	0.0%	77	100.0%
Gender * Model	77	100.0%	0	0.0%	77	100.0%
Exp * Model	77	100.0%	0	0.0%	77	100.0%
Ref * Model	77	100.0%	0	0.0%	77	100.0%
CHrs * Model	77	100.0%	0	0.0%	77	100.0%
CAD * Model	77	100.0%	0	0.0%	77	100.0%
Time * Model	77	100.0%	0	0.0%	77	100.0%
Seq1 * Model	77	100.0%	0	0.0%	77	100.0%
Seq2 * Model	77	100.0%	0	0.0%	77	100.0%
Seq3 * Model	77	100.0%	0	0.0%	77	100.0%
Seq4 * Model	77	100.0%	0	0.0%	77	100.0%
Seq5 * Model	77	100.0%	0	0.0%	77	100.0%
Comp * Model	77	100.0%	0	0.0%	77	100.0%
MD * Model	77	100.0%	0	0.0%	77	100.0%
PD * Model	77	100.0%	0	0.0%	77	100.0%
TD * Model	77	100.0%	0	0.0%	77	100.0%
OP * Model	77	100.0%	0	0.0%	77	100.0%
EF * Model	77	100.0%	0	0.0%	77	100.0%
FR * Model	77	100.0%	0	0.0%	77	100.0%
CR * Model	77	100.0%	0	0.0%	77	100.0%
CC * Model	77	100.0%	0	0.0%	77	100.0%
DW * Model	77	100.0%	0	0.0%	77	100.0%
IW * Model	77	100.0%	0	0.0%	77	100.0%
RW * Model	77	100.0%	0	0.0%	77	100.0%
DRW * Model	77	100.0%	0	0.0%	77	100.0%
TwoDPIF * Model	77	100.0%	0	0.0%	77	100.0%
ThrDPIF * Model	77	100.0%	0	0.0%	77	100.0%
SES2D * Model	77	100.0%	0	0.0%	77	100.0%
SES3D * Model	77	100.0%	0	0.0%	77	100.0%
CSP2D * Model	77	100.0%	0	0.0%	77	100.0%
CSP3D * Model	77	100.0%	0	0.0%	77	100.0%
MEP2D * Model	77	100.0%	0	0.0%	77	100.0%
MEP3D * Model	77	100.0%	0	0.0%	77	100.0%
CFQ2D * Model	77	100.0%	0	0.0%	77	100.0%

CFQ3D * Model	77	100.0%	0	0.0%	77	100.0%
MC * Model	77	100.0%	0	0.0%	77	100.0%

Report

	Model											
	0			1			2			Total		
	Mean	N	Std. Deviation	Mean	N	Std. Deviation	Mean	N	Std. Deviation	Mean	N	Std. Deviation
Age	40.69	26	11.235	40.69	26	11.235	40.04	25	10.952	40.48	77	11.001
Gender	.08	26	.272	.08	26	.272	.08	25	.277	.08	77	.270
Exp	16.4777	26	10.81151	16.4777	26	10.81151	15.9368	25	10.66937	16.3021	77	10.62608
Ref	7.69	26	2.396	7.69	26	2.396	7.64	25	2.430	7.68	77	2.376
CHrs	32.08	26	62.451	32.08	26	62.451	33.36	25	63.388	32.49	77	61.928
CAD	.35	26	.485	.35	26	.485	.36	25	.490	.35	77	.480
Time	10.0192	26	2.02158	11.7454	26	4.04745	10.3264	25	4.23489	10.7018	77	3.60206
Seq1	.12	26	.326	.12	26	.326	.12	25	.332	.12	77	.323
Seq2	.19	26	.402	.19	26	.402	.20	25	.408	.19	77	.399
Seq3	.19	26	.402	.19	26	.402	.20	25	.408	.19	77	.399
Seq4	.12	26	.326	.12	26	.326	.08	25	.277	.10	77	.307
Seq5	.19	26	.402	.19	26	.402	.20	25	.408	.19	77	.399
Comp	33.7177	26	14.54506	36.6342	26	17.30263	32.3412	25	16.76992	34.2556	77	16.12830
MD	39.42	26	21.969	44.04	26	22.540	36.20	25	22.880	39.94	77	22.397
PD	30.96	26	19.901	30.58	26	20.166	27.60	25	20.672	29.74	77	20.031
TD	45.38	26	26.227	44.23	26	24.807	43.20	25	24.575	44.29	77	24.904
OP	22.12	26	16.803	26.73	26	19.997	21.80	25	21.548	23.57	77	19.396
EF	40.77	26	22.614	44.42	26	25.820	42.20	25	25.045	42.47	77	24.247
FR	23.65	26	20.177	29.81	26	21.236	26.20	25	22.045	26.56	77	21.030
CR	91.65	26	39.732	91.65	26	39.732	91.28	25	40.505	91.53	77	39.455
CC	13.35	26	10.028	13.35	26	10.028	13.44	25	10.223	13.38	77	9.958

DW	75.5527	26	8.34767	66.6854	26	18.06075	87.7808	25	10.60495	76.5287	77	15.51959
IW	20.8500	26	6.71725	26.3296	26	11.84542	8.2452	25	4.92935	18.6078	77	11.23003
RW	3.4050	26	5.63713	5.8231	26	9.02576	3.9020	25	8.52918	4.3829	77	7.83173
DRW	.1923	26	.98058	1.0896	26	2.24644	.0716	25	.35800	.4561	77	1.49216
TwoDPIF	.46	26	.508	.46	26	.508	.48	25	.510	.47	77	.502
ThrDPIF	.15	26	.368	.15	26	.368	.16	25	.374	.16	77	.365
SES2D	.19	26	.402	.19	26	.402	.20	25	.408	.19	77	.399
SES3D	.58	26	.504	.58	26	.504	.56	25	.507	.57	77	.498
CSP2D	.62	26	.496	.62	26	.496	.64	25	.490	.62	77	.488
CSP3D	.38	26	.496	.38	26	.496	.36	25	.490	.38	77	.488
MEP2D	.15	26	.368	.15	26	.368	.16	25	.374	.16	77	.365
MEP3D	.77	26	.430	.77	26	.430	.76	25	.436	.77	77	.426
CFQ2D	.42	26	.504	.42	26	.504	.44	25	.507	.43	77	.498
CFQ3D	.58	26	.504	.58	26	.504	.56	25	.507	.57	77	.498
MC	.27	26	.452	.27	26	.452	.28	25	.458	.27	77	.448

ANOVA Table

			Sum of Squares	df	Mean Square	F	Sig.
Age * Model	Between Groups	(Combined)	7.184	2	3.592	.029	.972
	Within Groups		9190.037	74	124.190		
	Total		9197.221	76			
Gender * Model	Between Groups	(Combined)	.000	2	.000	.001	.999
	Within Groups		5.532	74	.075		
	Total		5.532	76			
Exp * Model	Between Groups	(Combined)	4.939	2	2.470	.021	.979
	Within Groups		8576.488	74	115.898		
	Total		8581.428	76			
Ref * Model	Between Groups	(Combined)	.046	2	.023	.004	.996
	Within Groups		428.837	74	5.795		
	Total		428.883	76			
CHrs * Model	Between Groups	(Combined)	27.794	2	13.897	.004	.996
	Within Groups		291441.452	74	3938.398		
	Total		291469.247	76			
CAD * Model	Between Groups	(Combined)	.003	2	.002	.007	.993
	Within Groups		17.529	74	.237		
	Total		17.532	76			
Time * Model	Between Groups	(Combined)	43.952	2	21.976	1.726	.185
	Within Groups		942.138	74	12.732		
	Total		986.090	76			
Seq1 * Model	Between Groups	(Combined)	.000	2	.000	.002	.998
	Within Groups		7.948	74	.107		
	Total		7.948	76			
Seq2 * Model	Between Groups	(Combined)	.001	2	.000	.003	.997
	Within Groups		12.077	74	.163		
	Total		12.078	76			

Seq3 * Model	Between Groups	(Combined)	.001	2	.000	.003	.997
	Within Groups		12.077	74	.163		
	Total		12.078	76			
Seq4 * Model	Between Groups	(Combined)	.021	2	.011	.109	.896
	Within Groups		7.148	74	.097		
	Total		7.169	76			
Seq5 * Model	Between Groups	(Combined)	.001	2	.000	.003	.997
	Within Groups		12.077	74	.163		
	Total		12.078	76			
Comp * Model	Between Groups	(Combined)	246.251	2	123.126	.467	.629
	Within Groups		19523.020	74	263.825		
	Total		19769.271	76			
MD * Model	Between Groups	(Combined)	793.368	2	396.684	.786	.459
	Within Groups		37331.308	74	504.477		
	Total		38124.675	76			
PD * Model	Between Groups	(Combined)	171.498	2	85.749	.209	.812
	Within Groups		30323.308	74	409.774		
	Total		30494.805	76			
TD * Model	Between Groups	(Combined)	60.945	2	30.473	.048	.953
	Within Groups		47074.769	74	636.146		
	Total		47135.714	76			
OP * Model	Between Groups	(Combined)	393.088	2	196.544	.516	.599
	Within Groups		28199.769	74	381.078		
	Total		28592.857	76			
EF * Model	Between Groups	(Combined)	176.207	2	88.104	.146	.864
	Within Groups		44504.962	74	601.418		
	Total		44681.169	76			
FR * Model	Between Groups	(Combined)	497.064	2	248.532	.555	.576
	Within Groups		33115.923	74	447.512		
	Total		33612.987	76			

CR * Model	Between Groups	(Combined)	2.360	2	1.180	.001	.999
	Within Groups		118306.809	74	1598.741		
	Total		118309.169	76			
CC * Model	Between Groups	(Combined)	.149	2	.074	.001	.999
	Within Groups		7535.929	74	101.837		
	Total		7536.078	76			
DW * Model	Between Groups	(Combined)	5709.174	2	2854.587	16.770	.000
	Within Groups		12596.020	74	170.216		
	Total		18305.193	76			
IW * Model	Between Groups	(Combined)	4365.588	2	2182.794	30.949	.000
	Within Groups		5219.050	74	70.528		
	Total		9584.638	76			
RW * Model	Between Groups	(Combined)	84.572	2	42.286	.684	.508
	Within Groups		4576.964	74	61.851		
	Total		4661.536	76			
DRW * Model	Between Groups	(Combined)	15.940	2	7.970	3.848	.026
	Within Groups		153.277	74	2.071		
	Total		169.217	76			
TwoDPIF * Model	Between Groups	(Combined)	.006	2	.003	.011	.989
	Within Groups		19.163	74	.259		
	Total		19.169	76			
ThrDPIF * Model	Between Groups	(Combined)	.001	2	.000	.002	.998
	Within Groups		10.129	74	.137		
	Total		10.130	76			
SES2D * Model	Between Groups	(Combined)	.001	2	.000	.003	.997
	Within Groups		12.077	74	.163		
	Total		12.078	76			
SES3D * Model	Between Groups	(Combined)	.005	2	.002	.009	.991
	Within Groups		18.852	74	.255		
	Total		18.857	76			

CSP2D * Model	Between Groups	(Combined)	.010	2	.005	.021	.979
	Within Groups		18.068	74	.244		
	Total		18.078	76			
CSP3D * Model	Between Groups	(Combined)	.010	2	.005	.021	.979
	Within Groups		18.068	74	.244		
	Total		18.078	76			
MEP2D * Model	Between Groups	(Combined)	.001	2	.000	.002	.998
	Within Groups		10.129	74	.137		
	Total		10.130	76			
MEP3D * Model	Between Groups	(Combined)	.001	2	.001	.004	.996
	Within Groups		13.791	74	.186		
	Total		13.792	76			
CFQ2D * Model	Between Groups	(Combined)	.005	2	.002	.009	.991
	Within Groups		18.852	74	.255		
	Total		18.857	76			
CFQ3D * Model	Between Groups	(Combined)	.005	2	.002	.009	.991
	Within Groups		18.852	74	.255		
	Total		18.857	76			
MC * Model	Between Groups	(Combined)	.002	2	.001	.005	.995
	Within Groups		15.271	74	.206		
	Total		15.273	76			

Measures of Association

	Eta	Eta Squared
Age * Model	.028	.001
Gender * Model	.005	.000
Exp * Model	.024	.001
Ref * Model	.010	.000
CHrs * Model	.010	.000
CAD * Model	.014	.000
Time * Model	.211	.045
Seq1 * Model	.007	.000
Seq2 * Model	.009	.000
Seq3 * Model	.009	.000
Seq4 * Model	.054	.003
Seq5 * Model	.009	.000
Comp * Model	.112	.012
MD * Model	.144	.021
PD * Model	.075	.006
TD * Model	.036	.001
OP * Model	.117	.014
EF * Model	.063	.004
FR * Model	.122	.015
CR * Model	.004	.000
CC * Model	.004	.000
DW * Model	.558	.312
IW * Model	.675	.455
RW * Model	.135	.018
DRW * Model	.307	.094
TwoDPIF * Model	.017	.000
ThrDPIF * Model	.008	.000
SES2D * Model	.009	.000
SES3D * Model	.016	.000
CSP2D * Model	.024	.001
CSP3D * Model	.024	.001
MEP2D * Model	.008	.000
MEP3D * Model	.010	.000
CFQ2D * Model	.016	.000
CFQ3D * Model	.016	.000
MC * Model	.011	.000

Appendix J: SPSS ANOVA Output, Students Only

Case Processing Summary

	Cases					
	Included		Excluded		Total	
	N	Percent	N	Percent	N	Percent
Age * Model	33	100.0%	0	0.0%	33	100.0%
Gender * Model	33	100.0%	0	0.0%	33	100.0%
Exp * Model	33	100.0%	0	0.0%	33	100.0%
Ref * Model	33	100.0%	0	0.0%	33	100.0%
CHrs * Model	33	100.0%	0	0.0%	33	100.0%
CAD * Model	33	100.0%	0	0.0%	33	100.0%
Time * Model	33	100.0%	0	0.0%	33	100.0%
Seq1 * Model	33	100.0%	0	0.0%	33	100.0%
Seq2 * Model	33	100.0%	0	0.0%	33	100.0%
Seq3 * Model	33	100.0%	0	0.0%	33	100.0%
Seq4 * Model	33	100.0%	0	0.0%	33	100.0%
Seq5 * Model	33	100.0%	0	0.0%	33	100.0%
Comp * Model	33	100.0%	0	0.0%	33	100.0%
MD * Model	33	100.0%	0	0.0%	33	100.0%
PD * Model	33	100.0%	0	0.0%	33	100.0%
TD * Model	33	100.0%	0	0.0%	33	100.0%
OP * Model	33	100.0%	0	0.0%	33	100.0%
EF * Model	33	100.0%	0	0.0%	33	100.0%
FR * Model	33	100.0%	0	0.0%	33	100.0%
CR * Model	33	100.0%	0	0.0%	33	100.0%
CC * Model	33	100.0%	0	0.0%	33	100.0%
DW * Model	33	100.0%	0	0.0%	33	100.0%
IW * Model	33	100.0%	0	0.0%	33	100.0%
RW * Model	33	100.0%	0	0.0%	33	100.0%
DRW * Model	33	100.0%	0	0.0%	33	100.0%
TwoDPIF * Model	33	100.0%	0	0.0%	33	100.0%
ThrDPIF * Model	33	100.0%	0	0.0%	33	100.0%
SES2D * Model	33	100.0%	0	0.0%	33	100.0%
SES3D * Model	33	100.0%	0	0.0%	33	100.0%
CSP2D * Model	33	100.0%	0	0.0%	33	100.0%
CSP3D * Model	33	100.0%	0	0.0%	33	100.0%
MEP2D * Model	33	100.0%	0	0.0%	33	100.0%
MEP3D * Model	33	100.0%	0	0.0%	33	100.0%
CFQ2D * Model	33	100.0%	0	0.0%	33	100.0%

CFQ3D * Model	33	100.0%	0	0.0%	33	100.0%
MC * Model	33	100.0%	0	0.0%	33	100.0%

Report

	Model											
	0			1			2			Total		
	Mean	N	Std. Deviation	Mean	N	Std. Deviation	Mean	N	Std. Deviation	Mean	N	Std. Deviation
Age	28.45	11	5.392	28.45	11	5.392	28.45	11	5.392	28.45	33	5.221
Gender	.18	11	.405	.18	11	.405	.18	11	.405	.18	33	.392
Exp	2.6291	11	3.71898	2.6291	11	3.71898	2.6291	11	3.71898	2.6291	33	3.60089
Ref	5.36	11	2.942	5.36	11	2.942	5.36	11	2.942	5.36	33	2.848
CHrs	93.27	11	64.205	93.27	11	64.205	93.27	11	64.205	93.27	33	62.166
CAD	.91	11	.302	.91	11	.302	.91	11	.302	.91	33	.292
Time	10.9936	11	3.39134	10.3500	11	2.49024	9.0573	11	1.51495	10.1336	33	2.63018
Seq1	.18	11	.405	.18	11	.405	.18	11	.405	.18	33	.392
Seq2	.18	11	.405	.18	11	.405	.18	11	.405	.18	33	.392
Seq3	.00	11	.000	.00	11	.000	.00	11	.000	.00	33	.000
Seq4	.27	11	.467	.27	11	.467	.27	11	.467	.27	33	.452
Seq5	.18	11	.405	.18	11	.405	.18	11	.405	.18	33	.392
Comp	32.8791	11	15.13015	29.3936	11	14.18301	26.1391	11	15.54727	29.4706	33	14.75627
MD	37.73	11	24.634	28.64	11	15.507	23.18	11	21.363	29.85	33	21.083
PD	23.64	11	17.620	24.55	11	16.501	25.45	11	17.952	24.55	33	16.834
TD	51.36	11	26.371	45.45	11	26.875	40.91	11	27.186	45.91	33	26.323
OP	19.09	11	13.751	20.45	11	17.242	15.45	11	16.040	18.33	33	15.394
EF	37.73	11	22.623	31.82	11	24.008	28.18	11	24.008	32.58	33	23.154
FR	27.73	11	22.289	25.45	11	19.806	23.64	11	25.504	25.61	33	22.000
CR	109.00	11	31.292	109.00	11	31.292	109.00	11	31.292	109.00	33	30.299
CC	19.27	11	9.624	19.27	11	9.624	19.27	11	9.624	19.27	33	9.318

DW	72.3182	11	9.69389	69.5809	11	12.06106	88.0464	11	5.21792	76.6485	33	12.31288
IW	22.1836	11	10.50355	24.9100	11	7.88449	9.3327	11	4.93519	18.8088	33	10.44475
RW	5.4991	11	5.45987	4.1609	11	6.52243	2.6182	11	3.91810	4.0927	33	5.36995
DRW	.0000	11	.00000	1.3482	11	2.49964	.0000	11	.00000	.4494	33	1.53919
TwoDPIF	.27	11	.467	.27	11	.467	.27	11	.467	.27	33	.452
ThrDPIF	.27	11	.467	.27	11	.467	.27	11	.467	.27	33	.452
SES2D	.18	11	.405	.18	11	.405	.18	11	.405	.18	33	.392
SES3D	.64	11	.505	.64	11	.505	.64	11	.505	.64	33	.489
CSP2D	.45	11	.522	.45	11	.522	.45	11	.522	.45	33	.506
CSP3D	.55	11	.522	.55	11	.522	.55	11	.522	.55	33	.506
MEP2D	.09	11	.302	.09	11	.302	.09	11	.302	.09	33	.292
MEP3D	.73	11	.467	.73	11	.467	.73	11	.467	.73	33	.452
CFQ2D	.36	11	.505	.36	11	.505	.36	11	.505	.36	33	.489
CFQ3D	.64	11	.505	.64	11	.505	.64	11	.505	.64	33	.489
MC	.09	11	.302	.09	11	.302	.09	11	.302	.09	33	.292

ANOVA Table[a]

			Sum of Squares	df	Mean Square	F	Sig.
Age * Model	Between Groups	(Combined)	.000	2	.000	.000	1.000
	Within Groups		872.182	30	29.073		
	Total		872.182	32			
Gender * Model	Between Groups	(Combined)	.000	2	.000	.000	1.000
	Within Groups		4.909	30	.164		
	Total		4.909	32			
Exp * Model	Between Groups	(Combined)	.000	2	.000	.000	1.000
	Within Groups		414.924	30	13.831		
	Total		414.924	32			
Ref * Model	Between Groups	(Combined)	.000	2	.000	.000	1.000
	Within Groups		259.636	30	8.655		
	Total		259.636	32			
CHrs * Model	Between Groups	(Combined)	.000	2	.000	.000	1.000
	Within Groups		123666.545	30	4122.218		
	Total		123666.545	32			
CAD * Model	Between Groups	(Combined)	.000	2	.000	.000	1.000
	Within Groups		2.727	30	.091		
	Total		2.727	32			
Time * Model	Between Groups	(Combined)	21.395	2	10.697	1.605	.218
	Within Groups		199.976	30	6.666		
	Total		221.370	32			
Seq1 * Model	Between Groups	(Combined)	.000	2	.000	.000	1.000
	Within Groups		4.909	30	.164		
	Total		4.909	32			
Seq2 * Model	Between Groups	(Combined)	.000	2	.000	.000	1.000
	Within Groups		4.909	30	.164		
	Total		4.909	32			

Seq4 * Model	Between Groups	(Combined)	.000	2	.000	.000	1.000
	Within Groups		6.545	30	.218		
	Total		6.545	32			
Seq5 * Model	Between Groups	(Combined)	.000	2	.000	.000	1.000
	Within Groups		4.909	30	.164		
	Total		4.909	32			
Comp * Model	Between Groups	(Combined)	249.950	2	124.975	.558	.578
	Within Groups		6717.969	30	223.932		
	Total		6967.918	32			
MD * Model	Between Groups	(Combined)	1187.879	2	593.939	1.367	.270
	Within Groups		13036.364	30	434.545		
	Total		14224.242	32			
PD * Model	Between Groups	(Combined)	18.182	2	9.091	.030	.970
	Within Groups		9050.000	30	301.667		
	Total		9068.182	32			
TD * Model	Between Groups	(Combined)	604.545	2	302.273	.420	.661
	Within Groups		21568.182	30	718.939		
	Total		22172.727	32			
OP * Model	Between Groups	(Combined)	146.970	2	73.485	.296	.746
	Within Groups		7436.364	30	247.879		
	Total		7583.333	32			
EF * Model	Between Groups	(Combined)	510.606	2	255.303	.460	.636
	Within Groups		16645.455	30	554.848		
	Total		17156.061	32			
FR * Model	Between Groups	(Combined)	92.424	2	46.212	.090	.914
	Within Groups		15395.455	30	513.182		
	Total		15487.879	32			
CR * Model	Between Groups	(Combined)	.000	2	.000	.000	1.000
	Within Groups		29376.000	30	979.200		
	Total		29376.000	32			

CC * Model	Between Groups	(Combined)	.000	2	.000	.000	1.000
	Within Groups		2778.545	30	92.618		
	Total		2778.545	32			
DW * Model	Between Groups	(Combined)	2184.752	2	1092.376	12.289	.000
	Within Groups		2666.675	30	88.889		
	Total		4851.427	32			
IW * Model	Between Groups	(Combined)	1522.511	2	761.256	11.602	.000
	Within Groups		1968.458	30	65.615		
	Total		3490.969	32			
RW * Model	Between Groups	(Combined)	45.725	2	22.862	.782	.467
	Within Groups		877.037	30	29.235		
	Total		922.762	32			
DRW * Model	Between Groups	(Combined)	13.329	2	6.665	3.200	.055
	Within Groups		62.482	30	2.083		
	Total		75.811	32			
TwoDPIF * Model	Between Groups	(Combined)	.000	2	.000	.000	1.000
	Within Groups		6.545	30	.218		
	Total		6.545	32			
ThrDPIF * Model	Between Groups	(Combined)	.000	2	.000	.000	1.000
	Within Groups		6.545	30	.218		
	Total		6.545	32			
SES2D * Model	Between Groups	(Combined)	.000	2	.000	.000	1.000
	Within Groups		4.909	30	.164		
	Total		4.909	32			
SES3D * Model	Between Groups	(Combined)	.000	2	.000	.000	1.000
	Within Groups		7.636	30	.255		
	Total		7.636	32			
CSP2D * Model	Between Groups	(Combined)	.000	2	.000	.000	1.000
	Within Groups		8.182	30	.273		
	Total		8.182	32			

CSP3D * Model	Between Groups	(Combined)	.000	2	.000	.000	1.000
	Within Groups		8.182	30	.273		
	Total		8.182	32			
MEP2D * Model	Between Groups	(Combined)	.000	2	.000	.000	1.000
	Within Groups		2.727	30	.091		
	Total		2.727	32			
MEP3D * Model	Between Groups	(Combined)	.000	2	.000	.000	1.000
	Within Groups		6.545	30	.218		
	Total		6.545	32			
CFQ2D * Model	Between Groups	(Combined)	.000	2	.000	.000	1.000
	Within Groups		7.636	30	.255		
	Total		7.636	32			
CFQ3D * Model	Between Groups	(Combined)	.000	2	.000	.000	1.000
	Within Groups		7.636	30	.255		
	Total		7.636	32			
MC * Model	Between Groups	(Combined)	.000	2	.000	.000	1.000
	Within Groups		2.727	30	.091		
	Total		2.727	32			

a. No variance within groups - statistics for Seq3 * Model cannot be computed.

Measures of Association

	Eta	Eta Squared
Age * Model	.000	.000
Gender * Model	.000	.000
Exp * Model	.000	.000
Ref * Model	.000	.000
CHrs * Model	.000	.000
CAD * Model	.000	.000
Time * Model	.311	.097
Seq1 * Model	.000	.000
Seq2 * Model	.000	.000
Seq4 * Model	.000	.000
Seq5 * Model	.000	.000
Comp * Model	.189	.036
MD * Model	.289	.084
PD * Model	.045	.002
TD * Model	.165	.027
OP * Model	.139	.019
EF * Model	.173	.030
FR * Model	.077	.006
CR * Model	.000	.000
CC * Model	.000	.000
DW * Model	.671	.450
IW * Model	.660	.436
RW * Model	.223	.050
DRW * Model	.419	.176
TwoDPIF * Model	.000	.000
ThrDPIF * Model	.000	.000
SES2D * Model	.000	.000
SES3D * Model	.000	.000
CSP2D * Model	.000	.000
CSP3D * Model	.000	.000
MEP2D * Model	.000	.000
MEP3D * Model	.000	.000
CFQ2D * Model	.000	.000
CFQ3D * Model	.000	.000
MC * Model	.000	.000

Appendix K: SPSS Multiple Regression Output, All Subjects

Time to Completion as Dependent Variable

Descriptive Statistics

	Mean	Std. Deviation	N
Time	10.6546	3.55495	90
Age	39.07	11.365	90
Gender	.10	.302	90
Exp	14.2807	11.41180	90
Ref	7.27	2.476	90
CHrs	39.53	62.432	90
CAD	.43	.498	90
TwoD	.33	.474	90
ThrD	.33	.474	90
Seq1	.17	.375	90
Seq2	.17	.375	90
Seq3	.17	.375	90
Seq4	.17	.375	90
Seq5	.17	.375	90
Comp	32.9928	15.77111	90
MD	37.78	22.324	90
PD	28.67	19.369	90
TD	43.72	24.363	90
OP	22.61	18.636	90
EF	40.44	24.039	90
FR	25.61	21.105	90
CR	94.68	38.305	90
CC	13.76	9.804	90
DW	77.0367	15.03096	90
IW	18.4360	11.23639	90
RW	4.0732	7.42292	90
DRW	.4330	1.43466	90
TwoDPIF	.43	.498	90
ThrDPIF	.17	.375	90
SES2D	.17	.375	90
SES3D	.57	.498	90
CSP2D	.60	.493	90
CSP3D	.40	.493	90
MEP2D	.13	.342	90
MEP3D	.77	.425	90

CFQ2D	.43	.498	90
CFQ3D	.57	.498	90
MC	.27	.445	90

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	MC, ThrD, CSP3D, SES2D, IW, CHrs, Gender, RW, Seq4, EF, ThrDPIF, Seq1, Seq5, TwoD, CR, MEP2D, OP, PD, TD, DRW, CFQ3D, Seq3, FR, Ref, TwoDPIF, CC, Age, SES3D, MEP3D, MD, CAD, Seq2, Exp, Comp[b]	.	Enter

a. Dependent Variable: Time

b. Tolerance = .000 limits reached.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.875[a]	.765	.620	2.19261

a. Predictors: (Constant), MC, ThrD, CSP3D, SES2D, IW, CHrs, Gender, RW, Seq4, EF, ThrDPIF, Seq1, Seq5, TwoD, CR, MEP2D, OP, PD, TD, DRW, CFQ3D, Seq3, FR, Ref, TwoDPIF, CC, Age, SES3D, MEP3D, MD, CAD, Seq2, Exp, Comp

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	860.337	34	25.304	5.263	.000[b]
	Residual	264.415	55	4.808		
	Total	1124.752	89			

a. Dependent Variable: Time

b. Predictors: (Constant), MC, ThrD, CSP3D, SES2D, IW, CHrs, Gender, RW, Seq4, EF, ThrDPIF, Seq1, Seq5, TwoD, CR, MEP2D, OP, PD, TD, DRW, CFQ3D, Seq3, FR, Ref, TwoDPIF, CC, Age, SES3D, MEP3D, MD, CAD, Seq2, Exp, Comp

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	5.149	4.296		1.198	.236
	Age	.107	.078	.342	1.369	.176
	Gender	1.738	1.846	.147	.942	.351
	Exp	-.152	.090	-.488	-1.686	.097
	Ref	.036	.210	.025	.170	.866
	CHrs	-.003	.015	-.046	-.171	.865
	CAD	-.367	1.750	-.051	-.210	.835
	TwoD	-.078	.670	-.010	-.117	.907
	ThrD	-.612	.654	-.082	-.936	.353
	Seq1	.644	1.778	.068	.362	.719
	Seq2	-.395	2.239	-.042	-.176	.861
	Seq3	.567	1.577	.060	.359	.721
	Seq4	1.735	1.691	.183	1.026	.310
	Seq5	-.192	1.079	-.020	-.178	.859
	Comp	-.011	.312	-.049	-.036	.972
	MD	.045	.055	.281	.818	.417
	PD	.017	.059	.094	.294	.770
	TD	-.003	.057	-.019	-.049	.961
	OP	-.012	.051	-.061	-.229	.819
	EF	.028	.057	.187	.487	.628
	FR	-.003	.057	-.017	-.050	.960
	CR	-.008	.010	-.082	-.757	.453
	CC	-.122	.060	-.338	-2.033	.047
	IW	.089	.028	.283	3.207	.002
	RW	.161	.051	.336	3.156	.003
	DRW	.324	.266	.131	1.217	.229
	TwoDPIF	-.424	1.363	-.059	-.311	.757
	ThrDPIF	-.157	1.409	-.017	-.111	.912
	SES2D	1.425	1.760	.150	.810	.421
	SES3D	.319	1.093	.045	.292	.772
	CSP3D	-.523	1.139	-.072	-.459	.648
	MEP2D	-1.792	1.615	-.172	-1.110	.272

	MEP3D	.897	1.474	.107	.608	.546
	CFQ3D	1.005	.843	.141	1.192	.238
	MC	-1.376	1.048	-.172	-1.313	.195

a. Dependent Variable: Time

Excluded Variables[a]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	DW	-25.976[b]	-3.486	.001	-.429	6.400E-005
	CSP2D	.[b]	.	.	.	.000
	CFQ2D	.[b]	.	.	.	.000

a. Dependent Variable: Time

b. Predictors in the Model: (Constant), MC, ThrD, CSP3D, SES2D, IW, CHrs, Gender, RW, Seq4, EF, ThrDPIF, Seq1, Seq5, TwoD, CR, MEP2D, OP, PD, TD, DRW, CFQ3D, Seq3, FR, Ref, TwoDPIF, CC, Age, SES3D, MEP3D, MD, CAD, Seq2, Exp, Comp

VIFs and Reduced Model, Time to Completion, All Subjects

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	5.149	4.296		1.198	.236		
	Age	.107	.078	.342	1.369	.176	.069	14.596
	Gender	1.738	1.846	.147	.942	.351	.174	5.739
	Exp	-.152	.090	-.488	-1.686	.097	.051	19.570
	Ref	.036	.210	.025	.170	.866	.199	5.014
	CHrs	-.003	.015	-.046	-.171	.865	.060	16.646
	CAD	-.367	1.750	-.051	-.210	.835	.071	14.084
	TwoD	-.078	.670	-.010	-.117	.907	.536	1.867
	ThrD	-.612	.654	-.082	-.936	.353	.562	1.780
	Seq1	.644	1.778	.068	.362	.719	.122	8.218
	Seq2	-.395	2.239	-.042	-.176	.861	.077	13.033
	Seq3	.567	1.577	.060	.359	.721	.155	6.464
	Seq4	1.735	1.691	.183	1.026	.310	.134	7.438
	Seq5	-.192	1.079	-.020	-.178	.859	.330	3.030
	Comp	-.011	.312	-.049	-.036	.972	.002	449.033
	MD	.045	.055	.281	.818	.417	.036	27.605
	PD	.017	.059	.094	.294	.770	.042	23.878
	TD	-.003	.057	-.019	-.049	.961	.028	35.792
	OP	-.012	.051	-.061	-.229	.819	.061	16.447
	EF	.028	.057	.187	.487	.628	.029	34.469
	FR	-.003	.057	-.017	-.050	.960	.037	26.794
	CR	-.012	.016	-.082	-.757	.453	.361	2.772
	CC	-.051	.025	-.338	-2.033	.047	.155	6.452
	IW	.089	.028	.283	3.207	.002	.550	1.818
	RW	.161	.051	.336	3.156	.003	.377	2.650
	DRW	.324	.266	.131	1.217	.229	.370	2.702
	TwoDPIF	-.424	1.363	-.059	-.311	.757	.117	8.544
	ThrDPIF	-.157	1.409	-.017	-.111	.912	.194	5.158
	SES2D	1.425	1.760	.150	.810	.421	.124	8.052
	SES3D	.319	1.093	.045	.292	.772	.182	5.490

CSP3D	-.523	1.139	-.072	-.459	.648	.171	5.831
MEP2D	-1.792	1.615	-.172	-1.110	.272	.177	5.643
MEP3D	.897	1.474	.107	.608	.546	.137	7.275
CFQ3D	1.005	.843	.141	1.192	.238	.306	3.265
MC	-1.376	1.048	-.172	-1.313	.195	.249	4.018

a. Dependent Variable: Time

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	MC, ThrD, CSP3D, SES2D, IW, Gender, RW, Seq4, Seq1, Seq5, MEP2D, CR, TwoD, SES3D, Ref, CFQ3D, DRW, Seq3, CC, MEP3D[b]	.	Enter

a. Dependent Variable: Time

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.815[a]	.664	.567	2.33960

a. Predictors: (Constant), MC, ThrD, CSP3D, SES2D, IW, Gender, RW, Seq4, Seq1, Seq5, MEP2D, CR, TwoD, SES3D, Ref, CFQ3D, DRW, Seq3, CC, MEP3D

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	747.064	20	37.353	6.824	.000[b]
	Residual	377.688	69	5.474		
	Total	1124.752	89			

a. Dependent Variable: Time

b. Predictors: (Constant), MC, ThrD, CSP3D, SES2D, IW, Gender, RW, Seq4, Seq1, Seq5, MEP2D, CR, TwoD, SES3D, Ref, CFQ3D, DRW, Seq3, CC, MEP3D

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	10.209	2.158		4.730	.000		
	Gender	1.115	1.180	.095	.944	.348	.485	2.062
	Ref	.119	.148	.083	.804	.424	.456	2.194
	TwoD	.177	.659	.024	.268	.790	.629	1.589
	ThrD	-.864	.634	-.115	-1.362	.178	.680	1.470
	Seq1	.092	.919	.010	.100	.920	.519	1.928
	Seq3	.653	1.017	.069	.643	.522	.424	2.360
	Seq4	1.508	.991	.159	1.521	.133	.445	2.245
	Seq5	.271	.896	.029	.302	.764	.546	1.833
	CR	-.011	.014	-.071	-.732	.467	.519	1.928
	CC	-.063	.018	-.415	-3.481	.001	.342	2.926
	IW	.104	.025	.328	4.160	.000	.784	1.275
	RW	.179	.050	.373	3.601	.001	.453	2.207
	DRW	.404	.256	.163	1.578	.119	.455	2.200
	SES2D	-1.860	1.200	-.196	-1.550	.126	.304	3.287
	SES3D	-1.109	.745	-.155	-1.487	.141	.446	2.244
	CSP3D	-.240	.817	-.033	-.294	.770	.379	2.637
	MEP2D	-.379	1.127	-.036	-.336	.738	.414	2.415
	MEP3D	.160	1.107	.019	.145	.885	.277	3.607
	CFQ3D	1.221	.745	.171	1.639	.106	.446	2.240
	MC	-2.153	.843	-.269	-2.554	.013	.438	2.285

a. Dependent Variable: Time

Composite Workload as Dependent Variable

Descriptive Statistics

	Mean	Std. Deviation	N
Comp	32.9928	15.77111	90
Age	39.07	11.365	90
Gender	.10	.302	90
Exp	14.2807	11.41180	90
Ref	7.27	2.476	90
CHrs	39.53	62.432	90
CAD	.43	.498	90
TwoD	.33	.474	90
ThrD	.33	.474	90
Time	10.6546	3.55495	90
Seq1	.17	.375	90
Seq2	.17	.375	90
Seq3	.17	.375	90
Seq4	.17	.375	90
Seq5	.17	.375	90
MD	37.78	22.324	90
PD	28.67	19.369	90
TD	43.72	24.363	90
OP	22.61	18.636	90
EF	40.44	24.039	90
FR	25.61	21.105	90
CR	94.68	38.305	90
CC	13.76	9.804	90
DW	77.0367	15.03096	90
IW	18.4360	11.23639	90
RW	4.0732	7.42292	90
DRW	.4330	1.43466	90
TwoDPIF	.43	.498	90
ThrDPIF	.17	.375	90
SES2D	.17	.375	90
SES3D	.57	.498	90
CSP2D	.60	.493	90
CSP3D	.40	.493	90
MEP2D	.13	.342	90
MEP3D	.77	.425	90
CFQ2D	.43	.498	90

CFQ3D	.57	.498	90
MC	.27	.445	90

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	MC, ThrD, CSP3D, SES2D, IW, CHrs, Gender, RW, Seq4, EF, ThrDPIF, Seq1, Seq5, TwoD, CR, MEP2D, OP, PD, TD, DRW, CFQ3D, Seq3, FR, Ref, Time, TwoDPIF, Age, SES3D, CC, MEP3D, MD, CAD, Seq2, Exp[b]	.	Enter

a. Dependent Variable: Comp

b. Tolerance = .000 limits reached.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.999[a]	.998	.996	.94674

a. Predictors: (Constant), MC, ThrD, CSP3D, SES2D, IW, CHrs, Gender, RW, Seq4, EF, ThrDPIF, Seq1, Seq5, TwoD, CR, MEP2D, OP, PD, TD, DRW, CFQ3D, Seq3, FR, Ref, Time, TwoDPIF, Age, SES3D, CC, MEP3D, MD, CAD, Seq2, Exp

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	22087.488	34	649.632	724.776	.000[b]
	Residual	49.298	55	.896		
	Total	22136.786	89			

a. Dependent Variable: Comp

b. Predictors: (Constant), MC, ThrD, CSP3D, SES2D, IW, CHrs, Gender, RW, Seq4, EF, ThrDPIF, Seq1, Seq5, TwoD, CR, MEP2D, OP, PD, TD, DRW, CFQ3D, Seq3, FR, Ref, Time, TwoDPIF, Age, SES3D, CC, MEP3D, MD, CAD, Seq2, Exp

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-1.265	1.871		-.676	.502
	Age	.001	.034	.001	.024	.981
	Gender	1.068	.790	.020	1.351	.182
	Exp	-.030	.040	-.022	-.761	.450
	Ref	.042	.091	.007	.459	.648
	CHrs	.000	.007	.001	.027	.978
	CAD	-.401	.754	-.013	-.532	.597
	TwoD	-.035	.289	-.001	-.122	.903
	ThrD	-.378	.280	-.011	-1.351	.182
	Time	-.002	.058	.000	-.036	.972
	Seq1	-1.294	.748	-.031	-1.728	.090
	Seq2	-1.261	.952	-.030	-1.325	.191
	Seq3	.056	.682	.001	.082	.935
	Seq4	-.060	.737	-.001	-.082	.935
	Seq5	-.045	.466	-.001	-.096	.924
	MD	.156	.011	.221	14.224	.000
	PD	.176	.009	.216	19.544	.000
	TD	.173	.008	.267	21.234	.000
	OP	.144	.010	.170	14.349	.000
	EF	.166	.010	.253	16.527	.000
	FR	.171	.009	.228	19.571	.000
	CR	.010	.004	.023	2.272	.027
	CC	-.041	.026	-.025	-1.534	.131
	IW	.019	.013	.013	1.437	.156
	RW	.018	.024	.008	.736	.465
	DRW	.138	.115	.013	1.204	.234
	TwoDPIF	.784	.580	.025	1.352	.182
	ThrDPIF	.650	.602	.015	1.081	.285
	SES2D	.406	.762	.010	.532	.597
	SES3D	-.095	.472	-.003	-.200	.842
	CSP3D	.308	.491	.010	.627	.534
	MEP2D	.379	.703	.008	.539	.592

	MEP3D	.497	.635	.013	.782	.437
	CFQ3D	.501	.362	.016	1.382	.173
	MC	.227	.458	.006	.496	.622

a. Dependent Variable: Comp

Excluded Variables[a]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
	DW	-.761[b]	-.868	.389	-.117	5.297E-005
1	CSP2D	.[b]	.	.	.	.000
	CFQ2D	.[b]	.	.	.	.000

a. Dependent Variable: Comp

b. Predictors in the Model: (Constant), MC, ThrD, CSP3D, SES2D, IW, CHrs, Gender, RW, Seq4, EF, ThrDPIF, Seq1, Seq5, TwoD, CR, MEP2D, OP, PD, TD, DRW, CFQ3D, Seq3, FR, Ref, Time, TwoDPIF, Age, SES3D, CC, MEP3D, MD, CAD, Seq2, Exp

VIFs and Reduced Model, Composite Workload, All Subjects

Coefficients^{a}

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	-1.265	1.871		-.676	.502		
	Age	.001	.034	.001	.024	.981	.066	15.094
	Gender	1.068	.790	.020	1.351	.182	.177	5.644
	Exp	-.030	.040	-.022	-.761	.450	.049	20.368
	Ref	.042	.091	.007	.459	.648	.200	4.997
	CHrs	.000	.007	.001	.027	.978	.060	16.655
	CAD	-.401	.754	-.013	-.532	.597	.071	14.023
	TwoD	-.035	.289	-.001	-.122	.903	.536	1.867
	ThrD	-.378	.280	-.011	-1.351	.182	.571	1.750
	Time	-.002	.058	.000	-.036	.972	.235	4.254
	Seq1	-1.294	.748	-.031	-1.728	.090	.128	7.813
	Seq2	-1.261	.952	-.030	-1.325	.191	.079	12.637
	Seq3	.056	.682	.001	.082	.935	.154	6.478
	Seq4	-.060	.737	-.001	-.082	.935	.132	7.579
	Seq5	-.045	.466	-.001	-.096	.924	.330	3.031
	MD	.156	.011	.221	14.224	.000	.167	5.972
	PD	.176	.009	.216	19.544	.000	.332	3.010
	TD	.173	.008	.267	21.234	.000	.257	3.892
	OP	.144	.010	.170	14.349	.000	.288	3.471
	EF	.166	.010	.253	16.527	.000	.172	5.802
	FR	.171	.009	.228	19.571	.000	.297	3.364
	CR	.015	.007	.023	2.272	.027	.391	2.560
	CC	-.017	.011	-.025	-1.534	.131	.150	6.652
	IW	.019	.013	.013	1.437	.156	.481	2.079
	RW	.018	.024	.008	.736	.465	.323	3.099
	DRW	.138	.115	.013	1.204	.234	.370	2.703
	TwoDPIF	.784	.580	.025	1.352	.182	.121	8.284
	ThrDPIF	.650	.602	.015	1.081	.285	.198	5.052
	SES2D	.406	.762	.010	.532	.597	.123	8.107
	SES3D	-.095	.472	-.003	-.200	.842	.182	5.495

	CSP3D	.308	.491	.010	.627	.534	.172	5.812
	MEP2D	.379	.703	.008	.539	.592	.174	5.739
	MEP3D	.497	.635	.013	.782	.437	.138	7.243
	CFQ3D	.501	.362	.016	1.382	.173	.309	3.237
	MC	.227	.458	.006	.496	.622	.242	4.126

a. Dependent Variable: Comp

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	MC, ThrD, CSP3D, SES2D, IW, FR, Seq5, ThrDPIF, DRW, Seq4, TD, Seq1, Ref, CR, PD, TwoD, OP, RW, Gender, MEP2D, CFQ3D, TwoDPIF, Seq3, Time, SES3D, CC, MEP3D, MD, EF[b]	.	Enter

a. Dependent Variable: Comp

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.999[a]	.998	.997	.93302

a. Predictors: (Constant), MC, ThrD, CSP3D, SES2D, IW, FR, Seq5, ThrDPIF, DRW, Seq4, TD, Seq1, Ref, CR, PD, TwoD, OP, RW, Gender, MEP2D, CFQ3D, TwoDPIF, Seq3, Time, SES3D, CC, MEP3D, MD, EF

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	22084.554	29	761.536	874.792	.000[b]
	Residual	52.232	60	.871		
	Total	22136.786	89			

a. Dependent Variable: Comp

b. Predictors: (Constant), MC, ThrD, CSP3D, SES2D, IW, FR, Seq5, ThrDPIF, DRW, Seq4, TD, Seq1, Ref, CR, PD, TwoD, OP, RW, Gender, MEP2D, CFQ3D, TwoDPIF, Seq3, Time, SES3D, CC, MEP3D, MD, EF

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	-1.870	1.139		-1.643	.106		
	Gender	.603	.665	.012	.907	.368	.243	4.113
	Ref	-.016	.073	-.002	-.216	.830	.302	3.311
	TwoD	-.012	.282	.000	-.042	.967	.549	1.821
	ThrD	-.379	.274	-.011	-1.382	.172	.579	1.726
	Time	.003	.056	.001	.046	.964	.251	3.982
	Seq1	-.409	.419	-.010	-.978	.332	.398	2.515
	Seq3	.512	.464	.012	1.103	.275	.323	3.093
	Seq4	.403	.477	.010	.844	.402	.306	3.271
	Seq5	.344	.373	.008	.921	.361	.500	2.001
	MD	.159	.010	.224	15.148	.000	.179	5.584
	PD	.171	.008	.210	21.150	.000	.399	2.505
	TD	.167	.007	.258	23.449	.000	.324	3.086
	OP	.143	.009	.170	15.727	.000	.338	2.954
	EF	.167	.010	.255	17.092	.000	.177	5.652
	FR	.175	.008	.234	22.417	.000	.361	2.772
	CR	.017	.006	.026	2.629	.011	.414	2.415
	CC	-.009	.008	-.013	-1.027	.309	.249	4.009
	IW	.022	.012	.016	1.853	.069	.530	1.886
	RW	.013	.023	.006	.561	.577	.347	2.883
	DRW	.109	.109	.010	1.000	.321	.402	2.487
	TwoDPIF	.552	.405	.017	1.361	.179	.240	4.173
	ThrDPIF	.630	.447	.015	1.407	.165	.348	2.875
	SES2D	.426	.668	.010	.638	.526	.156	6.403
	SES3D	.105	.417	.003	.252	.802	.227	4.407
	CSP3D	-.084	.403	-.003	-.208	.836	.248	4.026
	MEP2D	-.014	.534	.000	-.026	.980	.294	3.401
	MEP3D	.161	.484	.004	.332	.741	.231	4.330
	CFQ3D	.438	.343	.014	1.279	.206	.335	2.982
	MC	.588	.372	.017	1.578	.120	.357	2.802

a. Dependent Variable: Comp

Direct Work Rate as Dependent Variable

Descriptive Statistics

	Mean	Std. Deviation	N
DW	77.0367	15.03096	90
Age	39.07	11.365	90
Gender	.10	.302	90
Exp	14.2807	11.41180	90
Ref	7.27	2.476	90
CHrs	39.53	62.432	90
CAD	.43	.498	90
TwoD	.33	.474	90
ThrD	.33	.474	90
Time	10.6546	3.55495	90
Seq1	.17	.375	90
Seq2	.17	.375	90
Seq3	.17	.375	90
Seq4	.17	.375	90
Seq5	.17	.375	90
MD	37.78	22.324	90
PD	28.67	19.369	90
TD	43.72	24.363	90
OP	22.61	18.636	90
EF	40.44	24.039	90
FR	25.61	21.105	90
CR	94.68	38.305	90
CC	13.76	9.804	90
IW	18.4360	11.23639	90
RW	4.0732	7.42292	90
DRW	.4330	1.43466	90
TwoDPIF	.43	.498	90
ThrDPIF	.17	.375	90
SES2D	.17	.375	90
SES3D	.57	.498	90
CSP2D	.60	.493	90
CSP3D	.40	.493	90
MEP2D	.13	.342	90
MEP3D	.77	.425	90
CFQ2D	.43	.498	90

CFQ3D	.57	.498	90
MC	.27	.445	90
Comp	32.9928	15.77111	90

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Comp, Seq5, TwoDPIF, TwoD, CAD, CFQ3D, IW, Seq1, MC, ThrDPIF, DRW, MEP3D, Seq2, ThrD, Seq3, Ref, CR, RW, SES3D, CSP3D, PD, Age, Time, MEP2D, Seq4, Gender, OP, FR, CC, SES2D, MD, EF, CHrs, Exp, TD[b]	.	Enter

a. Dependent Variable: DW

b. Tolerance = .000 limits reached.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000[a]	1.000	1.000	.13948

a. Predictors: (Constant), Comp, Seq5, TwoDPIF, TwoD, CAD, CFQ3D, IW, Seq1, MC, ThrDPIF, DRW, MEP3D, Seq2, ThrD, Seq3, Ref, CR, RW, SES3D, CSP3D, PD, Age, Time, MEP2D, Seq4, Gender, OP, FR, CC, SES2D, MD, EF, CHrs, Exp, TD

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	20106.709	35	574.477	29530.919	.000[b]
	Residual	1.050	54	.019		
	Total	20107.759	89			

a. Dependent Variable: DW

b. Predictors: (Constant), Comp, Seq5, TwoDPIF, TwoD, CAD, CFQ3D, IW, Seq1, MC, ThrDPIF, DRW, MEP3D, Seq2, ThrD, Seq3, Ref, CR, RW, SES3D, CSP3D, PD, Age, Time, MEP2D, Seq4, Gender, OP, FR, CC, SES2D, MD, EF, CHrs, Exp, TD

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	99.316	.277		358.749	.000
	Age	.018	.005	.014	3.588	.001
	Gender	.194	.118	.004	1.641	.107
	Exp	-.012	.006	-.009	-2.035	.047
	Ref	-.012	.013	-.002	-.929	.357
	CHrs	.002	.001	.007	1.806	.077
	CAD	-.182	.111	-.006	-1.638	.107
	TwoD	.059	.043	.002	1.377	.174
	ThrD	.023	.042	.001	.554	.582
	Time	-.030	.009	-.007	-3.486	.001
	Seq1	.161	.113	.004	1.419	.162
	Seq2	.313	.142	.008	2.195	.032
	Seq3	.332	.100	.008	3.311	.002
	Seq4	.461	.109	.011	4.246	.000
	Seq5	.157	.069	.004	2.282	.026
	MD	.005	.004	.008	1.558	.125
	PD	.000	.004	.001	.124	.902
	TD	.002	.004	.003	.475	.636
	OP	.003	.003	.004	.912	.366
	EF	.000	.004	.000	.059	.953
	FR	.007	.004	.010	1.941	.058
	CR	-.001	.001	-.003	-1.646	.106
	CC	.007	.004	.005	1.746	.087
	IW	-.997	.002	-.745	-515.871	.000
	RW	-.992	.004	-.490	-281.549	.000
	DRW	-1.074	.017	-.102	-62.547	.000
	TwoDPIF	.158	.087	.005	1.826	.073
	ThrDPIF	.272	.090	.007	3.034	.004
	SES2D	.198	.113	.005	1.759	.084
	SES3D	.027	.070	.001	.381	.705
	CSP3D	-.171	.073	-.006	-2.357	.022
	MEP2D	-.248	.104	-.006	-2.382	.021

	MEP3D	.118	.094	.003	1.259	.213
	CFQ3D	.083	.054	.003	1.531	.132
	MC	.111	.068	.003	1.643	.106
	Comp	-.017	.020	-.018	-.868	.389

a. Dependent Variable: DW

Excluded Variables[a]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	CSP2D	.[b]	.	.	.	.000
	CFQ2D	.[b]	.	.	.	.000

a. Dependent Variable: DW

b. Predictors in the Model: (Constant), Comp, Seq5, TwoDPIF, TwoD, CAD, CFQ3D, IW, Seq1, MC, ThrDPIF, DRW, MEP3D, Seq2, ThrD, Seq3, Ref, CR, RW, SES3D, CSP3D, PD, Age, Time, MEP2D, Seq4, Gender, OP, FR, CC, SES2D, MD, EF, CHrs, Exp, TD

VIFs and Reduced Model, Direct Work Rate, All Subjects

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	99.316	.277		358.749	.000		
	Age	.018	.005	.014	3.588	.001	.066	15.094
	Gender	.194	.118	.004	1.641	.107	.171	5.831
	Exp	-.012	.006	-.009	-2.035	.047	.049	20.582
	Ref	-.012	.013	-.002	-.929	.357	.199	5.017
	CHrs	.002	.001	.007	1.806	.077	.060	16.655
	CAD	-.182	.111	-.006	-1.638	.107	.071	14.095
	TwoD	.059	.043	.002	1.377	.174	.535	1.867
	ThrD	.023	.042	.001	.554	.582	.553	1.808
	Time	-.030	.009	-.007	-3.486	.001	.235	4.254
	Seq1	.161	.113	.004	1.419	.162	.121	8.237
	Seq2	.313	.142	.008	2.195	.032	.077	13.040
	Seq3	.332	.100	.008	3.311	.002	.154	6.479
	Seq4	.461	.109	.011	4.246	.000	.132	7.580
	Seq5	.157	.069	.004	2.282	.026	.330	3.031
	Comp	-.017	.020	-.018	-.868	.389	.002	449.044
	MD	.005	.004	.008	1.558	.125	.036	27.941
	PD	.000	.004	.001	.124	.902	.042	23.915
	TD	.002	.004	.003	.475	.636	.028	35.794
	OP	.003	.003	.004	.912	.366	.061	16.463
	EF	.000	.004	.000	.059	.953	.029	34.618
	FR	.007	.004	.010	1.941	.058	.037	26.795
	CR	-.002	.001	-.003	-1.646	.106	.357	2.801
	CC	.003	.002	.005	1.746	.087	.144	6.936
	IW	-.997	.002	-.745	-515.871	.000	.464	2.157
	RW	-.992	.004	-.490	-281.549	.000	.320	3.130
	DRW	-1.074	.017	-.102	-62.547	.000	.360	2.775
	TwoDPIF	.158	.087	.005	1.826	.073	.117	8.560
	ThrDPIF	.272	.090	.007	3.034	.004	.194	5.159
	SES2D	.198	.113	.005	1.759	.084	.123	8.148

	SES3D	.027	.070	.001	.381	.705	.182	5.499
	CSP3D	-.171	.073	-.006	-2.357	.022	.171	5.854
	MEP2D	-.248	.104	-.006	-2.382	.021	.173	5.770
	MEP3D	.118	.094	.003	1.259	.213	.137	7.324
	CFQ3D	.083	.054	.003	1.531	.132	.299	3.349
	MC	.111	.068	.003	1.643	.106	.241	4.144

a. Dependent Variable: DW

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	MC, ThrD, CSP3D, SES2D, IW, Gender, RW, Seq4, Seq1, ThrDPIF, Seq5, TwoD, CR, MEP2D, DRW, SES3D, Ref, CFQ3D, TwoDPIF, Time, Seq3, CC, MEP3D[b]	.	Enter

a. Dependent Variable: DW

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000[a]	1.000	1.000	.16318

a. Predictors: (Constant), MC, ThrD, CSP3D, SES2D, IW, Gender, RW, Seq4, Seq1, ThrDPIF, Seq5, TwoD, CR, MEP2D, DRW, SES3D, Ref, CFQ3D, TwoDPIF, Time, Seq3, CC, MEP3D

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	20106.002	23	874.174	32827.630	.000[b]
	Residual	1.758	66	.027		
	Total	20107.759	89			

a. Dependent Variable: DW

b. Predictors: (Constant), MC, ThrD, CSP3D, SES2D, IW, Gender, RW, Seq4, Seq1, ThrDPIF, Seq5, TwoD, CR, MEP2D, DRW, SES3D, Ref, CFQ3D, TwoDPIF, Time, Seq3, CC, MEP3D

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	99.963	.188		530.570	.000		
	Gender	.168	.099	.003	1.707	.092	.338	2.954
	Ref	.005	.011	.001	.476	.636	.369	2.709
	TwoD	.009	.046	.000	.190	.850	.626	1.597
	ThrD	-.010	.045	.000	-.221	.826	.662	1.511
	Time	-.025	.008	-.006	-2.993	.004	.333	3.004
	Seq1	.013	.066	.000	.198	.844	.494	2.022
	Seq3	.119	.080	.003	1.476	.145	.330	3.035
	Seq4	.223	.083	.006	2.701	.009	.312	3.202
	Seq5	.025	.063	.001	.387	.700	.530	1.886
	CR	-.002	.001	-.004	-2.094	.040	.428	2.336
	CC	.002	.001	.003	1.475	.145	.277	3.615
	IW	-.997	.002	-.746	-499.361	.000	.594	1.683
	RW	-.992	.004	-.490	-259.565	.000	.372	2.689
	DRW	-1.072	.018	-.102	-58.645	.000	.435	2.301
	TwoDPIF	.052	.057	.002	.911	.365	.377	2.654
	ThrDPIF	.140	.074	.003	1.886	.064	.389	2.569
	SES2D	.148	.097	.004	1.526	.132	.225	4.439
	SES3D	.026	.055	.001	.462	.645	.392	2.549
	CSP3D	-.084	.064	-.003	-1.311	.195	.301	3.317
	MEP2D	-.003	.083	.000	-.034	.973	.371	2.694
	MEP3D	.099	.080	.003	1.231	.223	.256	3.912
	CFQ3D	.076	.056	.003	1.352	.181	.382	2.618
	MC	.050	.062	.001	.806	.423	.394	2.539

a. Dependent Variable: DW

Rework Rate as Dependent Variable

Descriptive Statistics

	Mean	Std. Deviation	N
RW	4.0732	7.42292	90
Age	39.07	11.365	90
Gender	.10	.302	90
Exp	14.2807	11.41180	90
Ref	7.27	2.476	90
CHrs	39.53	62.432	90
CAD	.43	.498	90
TwoD	.33	.474	90
ThrD	.33	.474	90
Time	10.6546	3.55495	90
Seq1	.17	.375	90
Seq2	.17	.375	90
Seq3	.17	.375	90
Seq4	.17	.375	90
Seq5	.17	.375	90
MD	37.78	22.324	90
PD	28.67	19.369	90
TD	43.72	24.363	90
OP	22.61	18.636	90
EF	40.44	24.039	90
FR	25.61	21.105	90
CR	94.68	38.305	90
CC	13.76	9.804	90
IW	18.4360	11.23639	90
DRW	.4330	1.43466	90
TwoDPIF	.43	.498	90
ThrDPIF	.17	.375	90
SES2D	.17	.375	90
SES3D	.57	.498	90
CSP2D	.60	.493	90
CSP3D	.40	.493	90
MEP2D	.13	.342	90
MEP3D	.77	.425	90
CFQ2D	.43	.498	90
CFQ3D	.57	.498	90
MC	.27	.445	90

Comp	32.9928	15.77111	90
DW	77.0367	15.03096	90

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	DW, MEP3D, Seq2, CC, ThrDPIF, ThrD, Seq4, EF, CAD, CSP3D, Seq5, TwoD, Seq1, Ref, TwoDPIF, TD, CR, CFQ3D, DRW, PD, FR, MC, Seq3, OP, SES3D, Time, Age, Gender, MEP2D, MD, IW, SES2D, CHrs, Exp, Comp[b]	.	Enter

a. Dependent Variable: RW

b. Tolerance = .000 limits reached.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000[a]	1.000	1.000	.14055

a. Predictors: (Constant), DW, MEP3D, Seq2, CC, ThrDPIF, ThrD, Seq4, EF, CAD, CSP3D, Seq5, TwoD, Seq1, Ref, TwoDPIF, TD, CR, CFQ3D, DRW, PD, FR, MC, Seq3, OP, SES3D, Time, Age, Gender, MEP2D, MD, IW, SES2D, CHrs, Exp, Comp

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	4902.808	35	140.080	7091.472	.000[b]
	Residual	1.067	54	.020		
	Total	4903.875	89			

a. Dependent Variable: RW

b. Predictors: (Constant), DW, MEP3D, Seq2, CC, ThrDPIF, ThrD, Seq4, EF, CAD, CSP3D, Seq5, TwoD, Seq1, Ref, TwoDPIF, TD, CR, CFQ3D, DRW, PD, FR, MC, Seq3, OP, SES3D, Time, Age, Gender, MEP2D, MD, IW, SES2D, CHrs, Exp, Comp

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	100.053	.415		241.248	.000
	Age	.018	.005	.028	3.538	.001
	Gender	.193	.119	.008	1.620	.111
	Exp	-.012	.006	-.018	-1.981	.053
	Ref	-.013	.013	-.004	-.954	.344
	CHrs	.002	.001	.015	1.790	.079
	CAD	-.181	.112	-.012	-1.610	.113
	TwoD	.061	.043	.004	1.425	.160
	ThrD	.024	.042	.002	.563	.576
	Time	-.029	.009	-.014	-3.393	.001
	Seq1	.161	.114	.008	1.407	.165
	Seq2	.316	.144	.016	2.200	.032
	Seq3	.335	.101	.017	3.308	.002
	Seq4	.460	.110	.023	4.188	.000
	Seq5	.160	.069	.008	2.313	.025
	MD	.005	.004	.016	1.534	.131
	PD	.000	.004	.001	.105	.917
	TD	.002	.004	.006	.464	.644
	OP	.003	.003	.007	.893	.376
	EF	.000	.004	.000	.029	.977
	FR	.007	.004	.020	1.940	.058
	CR	-.001	.001	-.006	-1.638	.107
	CC	.007	.004	.009	1.741	.087
	IW	-1.004	.003	-1.520	-287.008	.000
	DRW	-1.080	.019	-.209	-56.069	.000
	TwoDPIF	.158	.088	.011	1.806	.076
	ThrDPIF	.272	.090	.014	3.012	.004
	SES2D	.197	.114	.010	1.738	.088
	SES3D	.026	.070	.002	.372	.712
	CSP3D	-.170	.073	-.011	-2.320	.024
	MEP2D	-.248	.105	-.011	-2.367	.022
	MEP3D	.115	.095	.007	1.213	.231

	CFQ3D	.080	.055	.005	1.459	.150
	MC	.111	.068	.007	1.634	.108
	Comp	-.017	.020	-.036	-.849	.400
	DW	-1.007	.004	-2.040	-281.549	.000

a. Dependent Variable: RW

Excluded Variables[a]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	CSP2D	.[b]	.	.	.	.000
	CFQ2D	.[b]	.	.	.	.000

a. Dependent Variable: RW

b. Predictors in the Model: (Constant), DW, MEP3D, Seq2, CC, ThrDPIF, ThrD, Seq4, EF, CAD, CSP3D, Seq5, TwoD, Seq1, Ref, TwoDPIF, TD, CR, CFQ3D, DRW, PD, FR, MC, Seq3, OP, SES3D, Time, Age, Gender, MEP2D, MD, IW, SES2D, CHrs, Exp, Comp

VIFs and Reduced Model, Rework Rate, All Subjects

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	100.053	.415		241.248	.000		
	Age	.018	.005	.028	3.538	.001	.066	15.175
	Gender	.193	.119	.008	1.620	.111	.171	5.838
	Exp	-.012	.006	-.018	-1.981	.053	.048	20.660
	Ref	-.013	.013	-.004	-.954	.344	.200	5.012
	CHrs	.002	.001	.015	1.790	.079	.060	16.671
	CAD	-.181	.112	-.012	-1.610	.113	.071	14.118
	TwoD	.061	.043	.004	1.425	.160	.537	1.863
	ThrD	.024	.042	.002	.563	.576	.553	1.808
	Time	-.029	.009	-.014	-3.393	.001	.233	4.295
	Seq1	.161	.114	.008	1.407	.165	.121	8.242
	Seq2	.316	.144	.016	2.200	.032	.077	13.036
	Seq3	.335	.101	.017	3.308	.002	.154	6.480
	Seq4	.460	.110	.023	4.188	.000	.131	7.633
	Seq5	.160	.069	.008	2.313	.025	.331	3.024
	Comp	-.017	.020	-.036	-.849	.400	.002	449.318
	MD	.005	.004	.016	1.534	.131	.036	27.977
	PD	.000	.004	.001	.105	.917	.042	23.917
	TD	.002	.004	.006	.464	.644	.028	35.801
	OP	.003	.003	.007	.893	.376	.061	16.473
	EF	.000	.004	.000	.029	.977	.029	34.620
	FR	.007	.004	.020	1.940	.058	.037	26.796
	CR	-.002	.001	-.006	-1.638	.107	.357	2.802
	CC	.003	.002	.009	1.741	.087	.144	6.939
	DW	-1.007	.004	-2.040	-281.549	.000	.077	13.031
	IW	-1.004	.003	-1.520	-287.008	.000	.144	6.967
	DRW	-1.080	.019	-.209	-56.069	.000	.291	3.441
	TwoDPIF	.158	.088	.011	1.806	.076	.117	8.570
	ThrDPIF	.272	.090	.014	3.012	.004	.193	5.171
	SES2D	.197	.114	.010	1.738	.088	.123	8.159

	SES3D	.026	.070	.002	.372	.712	.182	5.500
	CSP3D	-.170	.073	-.011	-2.320	.024	.170	5.871
	MEP2D	-.248	.105	-.011	-2.367	.022	.173	5.777
	MEP3D	.115	.095	.007	1.213	.231	.136	7.339
	CFQ3D	.080	.055	.005	1.459	.150	.297	3.362
	MC	.111	.068	.007	1.634	.108	.241	4.146

a. Dependent Variable: RW

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	MC, ThrD, CSP3D, SES2D, IW, Gender, Seq4, Seq1, ThrDPIF, DRW, Seq5, MEP2D, CR, TwoD, Time, CFQ3D, Ref, SES3D, TwoDPIF, Seq3, CC, MEP3D[b]	.	Enter

a. Dependent Variable: RW

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.793[a]	.628	.506	5.21705

a. Predictors: (Constant), MC, ThrD, CSP3D, SES2D, IW, Gender, Seq4, Seq1, ThrDPIF, DRW, Seq5, MEP2D, CR, TwoD, Time, CFQ3D, Ref, SES3D, TwoDPIF, Seq3, CC, MEP3D

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	3080.292	22	140.013	5.144	.000[b]
	Residual	1823.583	67	27.218		
	Total	4903.875	89			

a. Dependent Variable: RW

b. Predictors: (Constant), MC, ThrD, CSP3D, SES2D, IW, Gender, Seq4, Seq1, ThrDPIF, DRW, Seq5, MEP2D, CR, TwoD, Time, CFQ3D, Ref, SES3D, TwoDPIF, Seq3, CC, MEP3D

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	5.018	5.992		.837	.405		
	Gender	-.931	3.149	-.038	-.296	.768	.339	2.950
	Ref	-.481	.363	-.161	-1.327	.189	.379	2.639
	TwoD	1.965	1.454	.125	1.351	.181	.643	1.554
	ThrD	-.503	1.432	-.032	-.351	.727	.663	1.508
	Time	.896	.246	.429	3.634	.001	.398	2.510
	Seq1	-3.155	2.063	-.159	-1.530	.131	.512	1.954
	Seq3	-.354	2.570	-.018	-.138	.891	.330	3.034
	Seq4	-6.120	2.532	-.309	-2.417	.018	.340	2.945
	Seq5	2.499	2.003	.126	1.248	.217	.543	1.843
	CR	.013	.035	.043	.374	.710	.429	2.331
	CC	-.014	.045	-.043	-.305	.761	.277	3.610
	IW	-.148	.061	-.224	-2.412	.019	.646	1.549
	DRW	2.205	.519	.426	4.250	.000	.552	1.812
	TwoDPIF	-.764	1.806	-.051	-.423	.673	.378	2.647
	ThrDPIF	-2.987	2.337	-.151	-1.279	.205	.399	2.507
	SES2D	-.878	3.107	-.044	-.283	.778	.226	4.434
	SES3D	.538	1.771	.036	.304	.762	.393	2.545
	CSP3D	3.475	2.000	.231	1.738	.087	.315	3.174
	MEP2D	2.754	2.634	.127	1.046	.300	.377	2.650
	MEP3D	-4.037	2.524	-.231	-1.599	.114	.265	3.769
	CFQ3D	-4.708	1.701	-.316	-2.767	.007	.426	2.350
	MC	-.291	1.981	-.017	-.147	.884	.394	2.538

a. Dependent Variable: RW

Appendix L:SPSS Multiple Regression Output, Practitioners Only

Time to Completion as Dependent Variable

Descriptive Statistics

	Mean	Std. Deviation	N
Time	10.6562	3.69491	78
Age	40.69	11.088	78
Gender	.08	.268	78
Exp	16.4777	10.67018	78
Ref	7.69	2.365	78
CHrs	32.08	61.635	78
CAD	.35	.479	78
TwoD	.33	.474	78
ThrD	.33	.474	78
Seq1	.12	.322	78
Seq2	.19	.397	78
Seq3	.19	.397	78
Seq4	.12	.322	78
Seq5	.19	.397	78
Comp	34.6177	15.76106	78
MD	40.45	22.407	78
PD	29.23	19.408	78
TD	45.13	24.455	78
OP	23.14	18.848	78
EF	43.59	23.602	78
FR	27.18	21.691	78
CR	92.19	38.941	78
CC	13.41	9.903	78
DW	77.1004	15.05099	78
IW	18.5583	11.34361	78
RW	4.0077	7.60134	78
DRW	.3095	1.19583	78
TwoDPIF	.46	.502	78
ThrDPIF	.15	.363	78
SES2D	.19	.397	78
SES3D	.58	.497	78
CSP2D	.62	.490	78
CSP3D	.38	.490	78
MEP2D	.15	.363	78
MEP3D	.77	.424	78

CFQ2D	.42	.497	78
CFQ3D	.58	.497	78
MC	.27	.446	78

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	MC, ThrD, ThrDPIF, MEP3D, Seq1, IW, PD, Seq4, CFQ3D, Seq5, CHrs, Ref, DRW, TD, CR, TwoD, FR, Seq3, RW, SES3D, OP, Seq2, TwoDPIF, EF, Age, CSP2D, MD, CC, Gender, MEP2D, CAD, SES2D, Exp, Comp[b]	.	Enter

a. Dependent Variable: Time

b. Tolerance = .000 limits reached.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.890[a]	.792	.628	2.25313

a. Predictors: (Constant), MC, ThrD, ThrDPIF, MEP3D, Seq1, IW, PD, Seq4, CFQ3D, Seq5, CHrs, Ref, DRW, TD, CR, TwoD, FR, Seq3, RW, SES3D, OP, Seq2, TwoDPIF, EF, Age, CSP2D, MD, CC, Gender, MEP2D, CAD, SES2D, Exp, Comp

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	832.938	34	24.498	4.826	.000[b]
	Residual	218.294	43	5.077		
	Total	1051.232	77			

a. Dependent Variable: Time

b. Predictors: (Constant), MC, ThrD, ThrDPIF, MEP3D, Seq1, IW, PD, Seq4, CFQ3D, Seq5, CHrs, Ref, DRW, TD, CR, TwoD, FR, Seq3, RW, SES3D, OP, Seq2, TwoDPIF, EF, Age, CSP2D, MD, CC, Gender, MEP2D, CAD, SES2D, Exp, Comp

Coefficients^{a}

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	6.154	5.555		1.108	.274
	Age	.148	.123	.443	1.205	.235
	Gender	2.142	3.364	.155	.637	.528
	Exp	-.270	.134	-.780	-2.013	.050
	Ref	.091	.309	.058	.294	.770
	CHrs	-.009	.017	-.157	-.552	.584
	CAD	.371	1.846	.048	.201	.842
	TwoD	-.143	.773	-.018	-.185	.854
	ThrD	-.586	.795	-.075	-.737	.465
	Seq1	1.757	2.432	.153	.722	.474
	Seq2	-1.750	3.131	-.188	-.559	.579
	Seq3	.322	1.900	.035	.170	.866
	Seq4	1.904	2.125	.166	.896	.375
	Seq5	-.709	1.175	-.076	-.604	.549
	Comp	.042	.335	.180	.126	.901
	MD	.030	.061	.183	.495	.623
	PD	-.014	.066	-.076	-.220	.827
	TD	-.020	.061	-.132	-.326	.746
	OP	-.022	.054	-.113	-.410	.684
	EF	.027	.062	.172	.437	.665
	FR	-.024	.063	-.139	-.376	.708
	CR	-.016	.012	-.164	-1.287	.205
	CC	-.146	.069	-.392	-2.106	.041
	IW	.094	.033	.290	2.863	.006
	RW	.189	.054	.389	3.486	.001
	DRW	.473	.357	.153	1.323	.193
	TwoDPIF	.381	1.762	.052	.216	.830
	ThrDPIF	-.008	1.548	-.001	-.005	.996
	SES2D	-.097	2.646	-.010	-.037	.971
	SES3D	.243	1.519	.033	.160	.874
	CSP2D	.994	1.415	.132	.703	.486
	MEP2D	-1.350	2.403	-.133	-.562	.577

	MEP3D	1.096	2.122	.126	.516	.608
	CFQ3D	1.462	.906	.197	1.614	.114
	MC	-2.028	1.394	-.245	-1.454	.153

a. Dependent Variable: Time

Excluded Variables[a]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	DW	-29.774[b]	-2.973	.005	-.417	4.073E-005
	CSP3D	.[b]	.	.	.	.000
	CFQ2D	.[b]	.	.	.	.000

a. Dependent Variable: Time

b. Predictors in the Model: (Constant), MC, ThrD, ThrDPIF, MEP3D, Seq1, IW, PD, Seq4, CFQ3D, Seq5, CHrs, Ref, DRW, TD, CR, TwoD, FR, Seq3, RW, SES3D, OP, Seq2, TwoDPIF, EF, Age, CSP2D, MD, CC, Gender, MEP2D, CAD, SES2D, Exp, Comp

VIFs and Reduced Model, Time to Completion, Practitioners Only

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	6.154	5.555		1.108	.274		
	Age	.148	.123	.443	1.205	.235	.036	28.037
	Gender	2.142	3.364	.155	.637	.528	.081	12.349
	Exp	-.270	.134	-.780	-2.013	.050	.032	31.068
	Ref	.091	.309	.058	.294	.770	.123	8.098
	CHrs	-.009	.017	-.157	-.552	.584	.060	16.771
	CAD	.371	1.846	.048	.201	.842	.084	11.853
	TwoD	-.143	.773	-.018	-.185	.854	.490	2.039
	ThrD	-.586	.795	-.075	-.737	.465	.463	2.159
	Seq1	1.757	2.432	.153	.722	.474	.108	9.277
	Seq2	-1.750	3.131	-.188	-.559	.579	.043	23.391
	Seq3	.322	1.900	.035	.170	.866	.116	8.615
	Seq4	1.904	2.125	.166	.896	.375	.141	7.080
	Seq5	-.709	1.175	-.076	-.604	.549	.304	3.292
	Comp	.042	.335	.180	.126	.901	.002	423.961
	MD	.030	.061	.183	.495	.623	.035	28.180
	PD	-.014	.066	-.076	-.220	.827	.040	24.716
	TD	-.020	.061	-.132	-.326	.746	.030	33.898
	OP	-.022	.054	-.113	-.410	.684	.063	15.789
	EF	.027	.062	.172	.437	.665	.031	32.274
	FR	-.024	.063	-.139	-.376	.708	.036	28.102
	CR	-.025	.019	-.164	-1.287	.205	.298	3.352
	CC	-.061	.029	-.392	-2.106	.041	.140	7.158
	IW	.094	.033	.290	2.863	.006	.471	2.124
	RW	.189	.054	.389	3.486	.001	.387	2.584
	DRW	.473	.357	.153	1.323	.193	.361	2.770
	TwoDPIF	.381	1.762	.052	.216	.830	.084	11.850
	ThrDPIF	-.008	1.548	-.001	-.005	.996	.209	4.794
	SES2D	-.097	2.646	-.010	-.037	.971	.060	16.713

	SES3D	.243	1.519	.033	.160	.874	.116	8.658
	CSP2D	.994	1.415	.132	.703	.486	.137	7.285
	MEP2D	-1.350	2.403	-.133	-.562	.577	.087	11.547
	MEP3D	1.096	2.122	.126	.516	.608	.081	12.286
	CFQ3D	1.462	.906	.197	1.614	.114	.325	3.075
	MC	-2.028	1.394	-.245	-1.454	.153	.170	5.876

a. Dependent Variable: Time

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	MC, ThrD, ThrDPIF, Seq5, IW, CFQ3D, Seq4, Seq1, Ref, DRW, CR, TwoD, CSP2D, RW, SES3D, Seq3, CC[b]	.	Enter

a. Dependent Variable: Time

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.792[a]	.627	.521	2.55730

a. Predictors: (Constant), MC, ThrD, ThrDPIF, Seq5, IW, CFQ3D, Seq4, Seq1, Ref, DRW, CR, TwoD, CSP2D, RW, SES3D, Seq3, CC

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	658.845	17	38.756	5.926	.000[b]
	Residual	392.387	60	6.540		
	Total	1051.232	77			

a. Dependent Variable: Time

b. Predictors: (Constant), MC, ThrD, ThrDPIF, Seq5, IW, CFQ3D, Seq4, Seq1, Ref, DRW, CR, TwoD, CSP2D, RW, SES3D, Seq3, CC

Coefficients^{a}

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	10.359	1.954		5.301	.000		
	Ref	-.029	.150	-.019	-.195	.846	.673	1.485
	TwoD	.170	.785	.022	.217	.829	.612	1.633
	ThrD	-.832	.751	-.107	-1.107	.273	.669	1.496
	Seq1	-.159	1.254	-.014	-.127	.900	.522	1.916
	Seq3	1.367	1.023	.147	1.337	.186	.516	1.937
	Seq4	1.598	1.127	.139	1.418	.161	.647	1.547
	Seq5	.568	.887	.061	.641	.524	.687	1.456
	CR	-.010	.017	-.065	-.598	.552	.519	1.926
	CC	-.065	.023	-.417	-2.780	.007	.277	3.607
	IW	.111	.030	.340	3.737	.000	.752	1.329
	RW	.151	.053	.310	2.830	.006	.520	1.925
	DRW	.682	.332	.221	2.052	.045	.537	1.861
	ThrDPIF	-.123	1.002	-.012	-.122	.903	.642	1.559
	SES3D	-.340	.811	-.046	-.419	.676	.523	1.913
	CSP2D	.495	.796	.066	.622	.536	.559	1.788
	CFQ3D	.946	.834	.127	1.134	.261	.494	2.023
	MC	-2.389	1.014	-.289	-2.356	.022	.414	2.413

a. Dependent Variable: Time

Composite Workload as Dependent Variable

Descriptive Statistics

	Mean	Std. Deviation	N
Comp	34.6177	15.76106	78
Age	40.69	11.088	78
Gender	.08	.268	78
Exp	16.4777	10.67018	78
Ref	7.69	2.365	78
CHrs	32.08	61.635	78
CAD	.35	.479	78
TwoD	.33	.474	78
ThrD	.33	.474	78
Seq1	.12	.322	78
Seq2	.19	.397	78
Seq3	.19	.397	78
Seq4	.12	.322	78
Seq5	.19	.397	78
MD	40.45	22.407	78
PD	29.23	19.408	78
TD	45.13	24.455	78
OP	23.14	18.848	78
EF	43.59	23.602	78
FR	27.18	21.691	78
CR	92.19	38.941	78
CC	13.41	9.903	78
DW	77.1004	15.05099	78
IW	18.5583	11.34361	78
RW	4.0077	7.60134	78
DRW	.3095	1.19583	78
TwoDPIF	.46	.502	78
ThrDPIF	.15	.363	78
SES2D	.19	.397	78
SES3D	.58	.497	78
CSP2D	.62	.490	78
CSP3D	.38	.490	78
MEP2D	.15	.363	78
MEP3D	.77	.424	78
CFQ2D	.42	.497	78
CFQ3D	.58	.497	78

MC	.27	.446	78
Time	10.6562	3.69491	78

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Time, Seq4, MC, MEP3D, Seq1, TwoD, ThrDPIF, Gender, CFQ3D, Seq5, CHrs, ThrD, EF, IW, DRW, CR, CSP2D, FR, TwoDPIF, SES3D, RW, Ref, PD, TD, Age, Seq3, OP, CC, MD, MEP2D, CAD, SES2D, Seq2, Exp[b]	.	Enter

a. Dependent Variable: Comp

b. Tolerance = .000 limits reached.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.999[a]	.998	.996	1.02413

a. Predictors: (Constant), Time, Seq4, MC, MEP3D, Seq1, TwoD, ThrDPIF, Gender, CFQ3D, Seq5, CHrs, ThrD, EF, IW, DRW, CR, CSP2D, FR, TwoDPIF, SES3D, RW, Ref, PD, TD, Age, Seq3, OP, CC, MD, MEP2D, CAD, SES2D, Seq2, Exp

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	19082.540	34	561.251	535.118	.000[b]
	Residual	45.100	43	1.049		
	Total	19127.640	77			

a. Dependent Variable: Comp

b. Predictors: (Constant), Time, Seq4, MC, MEP3D, Seq1, TwoD, ThrDPIF, Gender, CFQ3D, Seq5, CHrs, ThrD, EF, IW, DRW, CR, CSP2D, FR, TwoDPIF, SES3D, RW, Ref, PD, TD, Age, Seq3, OP, CC, MD, MEP2D, CAD, SES2D, Seq2, Exp

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-2.093	2.541		-.824	.415
	Age	.019	.057	.013	.333	.741
	Gender	-.123	1.536	-.002	-.080	.936
	Exp	-.008	.064	-.006	-.131	.897
	Ref	-.083	.140	-.012	-.591	.558
	CHrs	.002	.008	.008	.264	.793
	CAD	-.366	.838	-.011	-.437	.664
	TwoD	-.008	.351	.000	-.022	.983
	ThrD	-.372	.359	-.011	-1.036	.306
	Seq1	-.847	1.105	-.017	-.766	.448
	Seq2	.078	1.428	.002	.055	.957
	Seq3	.404	.862	.010	.469	.641
	Seq4	.255	.974	.005	.262	.795
	Seq5	.135	.536	.003	.252	.802
	MD	.159	.013	.227	11.941	.000
	PD	.178	.013	.219	14.252	.000
	TD	.169	.011	.262	16.083	.000
	OP	.135	.013	.162	10.037	.000
	EF	.167	.012	.250	13.772	.000
	FR	.175	.010	.241	17.393	.000
	CR	.012	.005	.031	2.370	.022
	CC	-.025	.033	-.016	-.764	.449
	IW	.017	.016	.012	1.038	.305
	RW	.010	.028	.005	.349	.729
	DRW	.226	.162	.017	1.393	.171
	TwoDPIF	.294	.800	.009	.367	.715
	ThrDPIF	.530	.699	.012	.759	.452
	SES2D	.959	1.194	.024	.803	.426
	SES3D	.251	.690	.008	.365	.717
	CSP2D	.027	.647	.001	.042	.967
	MEP2D	-.256	1.095	-.006	-.234	.816
	MEP3D	.159	.967	.004	.164	.870

	CFQ3D	.480	.418	.015	1.150	.257
	MC	.648	.642	.018	1.010	.318
	Time	.009	.069	.002	.126	.901

a. Dependent Variable: Comp

Excluded Variables[a]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	DW	-.124[b]	-.096	.924	-.015	3.366E-005
	CSP3D	.[b]	.	.	.	.000
	CFQ2D	.[b]	.	.	.	.000

a. Dependent Variable: Comp

b. Predictors in the Model: (Constant), Time, Seq4, MC, MEP3D, Seq1, TwoD, ThrDPIF, Gender, CFQ3D, Seq5, CHrs, ThrD, EF, IW, DRW, CR, CSP2D, FR, TwoDPIF, SES3D, RW, Ref, PD, TD, Age, Seq3, OP, CC, MD, MEP2D, CAD, SES2D, Seq2, Exp

VIFs and Reduced Model, Composite Workload, Practitioners Only

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	-2.093	2.541		-.824	.415		
	Age	.019	.057	.013	.333	.741	.035	28.909
	Gender	-.123	1.536	-.002	-.080	.936	.080	12.464
	Exp	-.008	.064	-.006	-.131	.897	.029	33.982
	Ref	-.083	.140	-.012	-.591	.558	.124	8.049
	CHrs	.002	.008	.008	.264	.793	.059	16.862
	CAD	-.366	.838	-.011	-.437	.664	.085	11.812
	TwoD	-.008	.351	.000	-.022	.983	.490	2.041
	ThrD	-.372	.359	-.011	-1.036	.306	.469	2.133
	Time	.009	.069	.002	.126	.901	.208	4.814
	Seq1	-.847	1.105	-.017	-.766	.448	.108	9.263
	Seq2	.078	1.428	.002	.055	.957	.042	23.559
	Seq3	.404	.862	.010	.469	.641	.117	8.577
	Seq4	.255	.974	.005	.262	.795	.139	7.201
	Seq5	.135	.536	.003	.252	.802	.302	3.315
	MD	.159	.013	.227	11.941	.000	.152	6.567
	PD	.178	.013	.219	14.252	.000	.231	4.323
	TD	.169	.011	.262	16.083	.000	.206	4.844
	OP	.135	.013	.162	10.037	.000	.211	4.742
	EF	.167	.012	.250	13.772	.000	.167	5.991
	FR	.175	.010	.241	17.393	.000	.285	3.509
	CR	.020	.008	.031	2.370	.022	.325	3.079
	CC	-.011	.014	-.016	-.764	.449	.128	7.791
	IW	.017	.016	.012	1.038	.305	.405	2.467
	RW	.010	.028	.005	.349	.729	.303	3.304
	DRW	.226	.162	.017	1.393	.171	.363	2.758
	TwoDPIF	.294	.800	.009	.367	.715	.085	11.826
	ThrDPIF	.530	.699	.012	.759	.452	.211	4.731
	SES2D	.959	1.194	.024	.803	.426	.061	16.467

	SES3D	.251	.690	.008	.365	.717	.116	8.636
	CSP2D	.027	.647	.001	.042	.967	.136	7.368
	MEP2D	-.256	1.095	-.006	-.234	.816	.086	11.617
	MEP3D	.159	.967	.004	.164	.870	.081	12.355
	CFQ3D	.480	.418	.015	1.150	.257	.316	3.164
	MC	.648	.642	.018	1.010	.318	.166	6.022

a. Dependent Variable: Comp

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	MC, ThrD, ThrDPIF, Seq5, EF, CFQ3D, IW, Seq4, Seq1, Ref, DRW, CR, FR, TwoD, Seq3, SES3D, RW, OP, PD, TD, Time, CC, MD[b]	.	Enter

a. Dependent Variable: Comp

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.999[a]	.997	.996	.95102

a. Predictors: (Constant), MC, ThrD, ThrDPIF, Seq5, EF, CFQ3D, IW, Seq4, Seq1, Ref, DRW, CR, FR, TwoD, Seq3, SES3D, RW, OP, PD, TD, Time, CC, MD

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	19078.801	23	829.513	917.166	.000[b]
	Residual	48.839	54	.904		
	Total	19127.640	77			

a. Dependent Variable: Comp

b. Predictors: (Constant), MC, ThrD, ThrDPIF, Seq5, EF, CFQ3D, IW, Seq4, Seq1, Ref, DRW, CR, FR, TwoD, Seq3, SES3D, RW, OP, PD, TD, Time, CC, MD

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	-.422	.916		-.461	.647		
	Ref	-.022	.063	-.003	-.342	.734	.527	1.898
	TwoD	.054	.320	.002	.168	.867	.511	1.956
	ThrD	-.351	.325	-.011	-1.080	.285	.494	2.026
	Time	-.022	.055	-.005	-.394	.695	.285	3.510
	Seq1	-.687	.504	-.014	-1.363	.179	.447	2.237
	Seq3	.003	.425	.000	.007	.995	.413	2.421
	Seq4	.165	.440	.003	.376	.708	.587	1.704
	Seq5	-.006	.349	.000	-.018	.985	.612	1.635
	MD	.164	.010	.233	16.129	.000	.227	4.396
	PD	.171	.009	.211	18.560	.000	.366	2.736
	TD	.167	.007	.259	23.183	.000	.379	2.639
	OP	.130	.009	.156	14.518	.000	.411	2.436
	EF	.167	.010	.250	16.282	.000	.201	4.973
	FR	.175	.007	.241	23.716	.000	.459	2.178
	CR	.019	.007	.029	2.831	.007	.464	2.156
	CC	-.015	.009	-.022	-1.552	.127	.235	4.261
	IW	.015	.014	.010	1.062	.293	.485	2.063
	RW	.018	.022	.009	.788	.434	.403	2.482
	DRW	.245	.145	.019	1.690	.097	.391	2.556
	ThrDPIF	.231	.419	.005	.552	.583	.508	1.970
	SES3D	-.152	.353	-.005	-.431	.668	.382	2.619
	CFQ3D	.500	.286	.016	1.750	.086	.582	1.718
	MC	.567	.410	.016	1.385	.172	.351	2.847

a. Dependent Variable: Comp

Direct Work Rate as Dependent Variable

Descriptive Statistics

	Mean	Std. Deviation	N
DW	77.1004	15.05099	78
Age	40.69	11.088	78
Gender	.08	.268	78
Exp	16.4777	10.67018	78
Ref	7.69	2.365	78
CHrs	32.08	61.635	78
CAD	.35	.479	78
TwoD	.33	.474	78
ThrD	.33	.474	78
Seq1	.12	.322	78
Seq2	.19	.397	78
Seq3	.19	.397	78
Seq4	.12	.322	78
Seq5	.19	.397	78
MD	40.45	22.407	78
PD	29.23	19.408	78
TD	45.13	24.455	78
OP	23.14	18.848	78
EF	43.59	23.602	78
FR	27.18	21.691	78
CR	92.19	38.941	78
CC	13.41	9.903	78
IW	18.5583	11.34361	78
RW	4.0077	7.60134	78
DRW	.3095	1.19583	78
TwoDPIF	.46	.502	78
ThrDPIF	.15	.363	78
SES2D	.19	.397	78
SES3D	.58	.497	78
CSP2D	.62	.490	78
CSP3D	.38	.490	78
MEP2D	.15	.363	78
MEP3D	.77	.424	78
CFQ2D	.42	.497	78
CFQ3D	.58	.497	78
MC	.27	.446	78

Time	10.6562	3.69491	78
Comp	34.6177	15.76106	78

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Comp, CAD, CR, Seq5, TwoD, Ref, Seq3, IW, CFQ3D, Seq1, ThrDPIF, MEP3D, ThrD, Seq4, DRW, MC, SES3D, RW, TwoDPIF, Seq2, FR, Time, PD, Age, OP, CSP2D, CC, MEP2D, MD, Gender, EF, SES2D, CHrs, TD, Exp[b]	.	Enter

a. Dependent Variable: DW

b. Tolerance = .000 limits reached.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000[a]	1.000	1.000	.11822

a. Predictors: (Constant), Comp, CAD, CR, Seq5, TwoD, Ref, Seq3, IW, CFQ3D, Seq1, ThrDPIF, MEP3D, ThrD, Seq4, DRW, MC, SES3D, RW, TwoDPIF, Seq2, FR, Time, PD, Age, OP, CSP2D, CC, MEP2D, MD, Gender, EF, SES2D, CHrs, TD, Exp

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	17442.400	35	498.354	35659.919	.000[b]
	Residual	.587	42	.014		
	Total	17442.987	77			

a. Dependent Variable: DW

b. Predictors: (Constant), Comp, CAD, CR, Seq5, TwoD, Ref, Seq3, IW, CFQ3D, Seq1, ThrDPIF, MEP3D, ThrD, Seq4, DRW, MC, SES3D, RW, TwoDPIF, Seq2, FR, Time, PD, Age, OP, CSP2D, CC, MEP2D, MD, Gender, EF, SES2D, CHrs, TD, Exp

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	99.267	.296		335.855	.000
	Age	.006	.007	.005	.950	.347
	Gender	.616	.177	.011	3.474	.001
	Exp	-.001	.007	-.001	-.138	.891
	Ref	.021	.016	.003	1.299	.201
	CHrs	.001	.001	.005	1.413	.165
	CAD	-.207	.097	-.007	-2.134	.039
	TwoD	.062	.041	.002	1.534	.133
	ThrD	.028	.042	.001	.676	.503
	Seq1	-.106	.128	-.002	-.824	.414
	Seq2	.022	.165	.001	.135	.893
	Seq3	.281	.100	.007	2.815	.007
	Seq4	.269	.113	.006	2.390	.021
	Seq5	.178	.062	.005	2.882	.006
	MD	.003	.003	.004	.888	.380
	PD	-.003	.003	-.003	-.733	.468
	TD	.000	.003	.000	-.067	.947
	OP	.003	.003	.004	1.132	.264
	EF	-.002	.003	-.002	-.469	.642
	FR	.004	.003	.005	1.116	.271
	CR	-.001	.001	-.003	-2.070	.045
	CC	.007	.004	.004	1.707	.095
	IW	-.999	.002	-.753	-528.718	.000
	RW	-.994	.003	-.502	-308.149	.000
	DRW	-1.119	.019	-.089	-58.522	.000
	TwoDPIF	.078	.092	.003	.838	.407
	ThrDPIF	.250	.081	.006	3.077	.004
	SES2D	.342	.139	.009	2.466	.018
	SES3D	.002	.080	.000	.029	.977
	CSP2D	.061	.075	.002	.823	.415
	MEP2D	-.042	.127	-.001	-.329	.744
	MEP3D	.184	.112	.005	1.647	.107

	CFQ3D	.039	.049	.001	.806	.425
	MC	.037	.075	.001	.488	.628
	Time	-.024	.008	-.006	-2.973	.005
	Comp	-.002	.018	-.002	-.096	.924

a. Dependent Variable: DW

Excluded Variables[a]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	CSP3D	.[b]	.	.	.	.000
	CFQ2D	.[b]	.	.	.	.000

a. Dependent Variable: DW

b. Predictors in the Model: (Constant), Comp, CAD, CR, Seq5, TwoD, Ref, Seq3, IW, CFQ3D, Seq1, ThrDPIF, MEP3D, ThrD, Seq4, DRW, MC, SES3D, RW, TwoDPIF, Seq2, FR, Time, PD, Age, OP, CSP2D, CC, MEP2D, MD, Gender, EF, SES2D, CHrs, TD, Exp

VIFs and Reduced Model, Direct Work Rate, Practitioners Only

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	99.267	.296		335.855	.000		
	Age	.006	.007	.005	.950	.347	.035	28.984
	Gender	.616	.177	.011	3.474	.001	.080	12.466
	Exp	-.001	.007	-.001	-.138	.891	.029	33.996
	Ref	.021	.016	.003	1.299	.201	.123	8.114
	CHrs	.001	.001	.005	1.413	.165	.059	16.889
	CAD	-.207	.097	-.007	-2.134	.039	.084	11.864
	TwoD	.062	.041	.002	1.534	.133	.490	2.041
	ThrD	.028	.042	.001	.676	.503	.457	2.186
	Time	-.024	.008	-.006	-2.973	.005	.208	4.816
	Seq1	-.106	.128	-.002	-.824	.414	.107	9.389
	Seq2	.022	.165	.001	.135	.893	.042	23.561
	Seq3	.281	.100	.007	2.815	.007	.116	8.621
	Seq4	.269	.113	.006	2.390	.021	.139	7.213
	Seq5	.178	.062	.005	2.882	.006	.301	3.320
	Comp	-.002	.018	-.002	-.096	.924	.002	424.116
	MD	.003	.003	.004	.888	.380	.035	28.341
	PD	-.003	.003	-.003	-.733	.468	.040	24.744
	TD	.000	.003	.000	-.067	.947	.029	33.982
	OP	.003	.003	.004	1.132	.264	.063	15.851
	EF	-.002	.003	-.002	-.469	.642	.031	32.417
	FR	.004	.003	.005	1.116	.271	.035	28.195
	CR	-.002	.001	-.003	-2.070	.045	.287	3.481
	CC	.003	.002	.004	1.707	.095	.127	7.897
	IW	-.999	.002	-.753	-528.718	.000	.395	2.529
	RW	-.994	.003	-.502	-308.149	.000	.302	3.314
	DRW	-1.119	.019	-.089	-58.522	.000	.347	2.882
	TwoDPIF	.078	.092	.003	.838	.407	.084	11.863
	ThrDPIF	.250	.081	.006	3.077	.004	.209	4.794

	SES2D	.342	.139	.009	2.466	.018	.060	16.714
	SES3D	.002	.080	.000	.029	.977	.115	8.663
	CSP2D	.061	.075	.002	.823	.415	.136	7.368
	MEP2D	-.042	.127	-.001	-.329	.744	.086	11.632
	MEP3D	.184	.112	.005	1.647	.107	.081	12.362
	CFQ3D	.039	.049	.001	.806	.425	.307	3.262
	MC	.037	.075	.001	.488	.628	.162	6.165

a. Dependent Variable: DW

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	MC, ThrD, ThrDPIF, Seq5, IW, CFQ3D, Seq4, Seq1, Ref, DRW, CR, TwoD, CSP2D, RW, SES3D, Seq3, Time, CC[b]	.	Enter

a. Dependent Variable: DW

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000[a]	1.000	1.000	.14526

a. Predictors: (Constant), MC, ThrD, ThrDPIF, Seq5, IW, CFQ3D, Seq4, Seq1, Ref, DRW, CR, TwoD, CSP2D, RW, SES3D, Seq3, Time, CC

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	17441.742	18	968.986	45921.185	.000[b]
	Residual	1.245	59	.021		
	Total	17442.987	77			

a. Dependent Variable: DW

b. Predictors: (Constant), MC, ThrD, ThrDPIF, Seq5, IW, CFQ3D, Seq4, Seq1, Ref, DRW, CR, TwoD, CSP2D, RW, SES3D, Seq3, Time, CC

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	100.194	.135		744.854	.000		
	Ref	.010	.009	.002	1.185	.241	.673	1.486
	TwoD	.013	.045	.000	.284	.777	.612	1.634
	ThrD	-.026	.043	-.001	-.595	.554	.655	1.526
	Time	-.019	.007	-.005	-2.635	.011	.373	2.679
	Seq1	-.091	.071	-.002	-1.270	.209	.522	1.916
	Seq3	-.034	.059	-.001	-.583	.562	.501	1.995
	Seq4	.103	.065	.002	1.584	.118	.626	1.599
	Seq5	.005	.051	.000	.107	.915	.682	1.466
	CR	-.002	.001	-.004	-2.593	.012	.516	1.938
	CC	.001	.001	.001	.538	.592	.246	4.072
	IW	-.998	.002	-.752	-534.343	.000	.610	1.639
	RW	-.993	.003	-.501	-308.628	.000	.458	2.182
	DRW	-1.130	.020	-.090	-57.849	.000	.502	1.991
	ThrDPIF	.007	.057	.000	.116	.908	.641	1.559
	SES3D	-.030	.046	-.001	-.640	.524	.521	1.919
	CSP2D	.013	.045	.000	.282	.779	.556	1.799
	CFQ3D	.038	.048	.001	.802	.426	.484	2.067
	MC	.004	.060	.000	.074	.941	.379	2.636

a. Dependent Variable: DW

Rework Rate as Dependent Variable

Descriptive Statistics

	Mean	Std. Deviation	N
RW	4.0077	7.60134	78
Age	40.69	11.088	78
Gender	.08	.268	78
Exp	16.4777	10.67018	78
Ref	7.69	2.365	78
CHrs	32.08	61.635	78
CAD	.35	.479	78
TwoD	.33	.474	78
ThrD	.33	.474	78
Seq1	.12	.322	78
Seq2	.19	.397	78
Seq3	.19	.397	78
Seq4	.12	.322	78
Seq5	.19	.397	78
MD	40.45	22.407	78
PD	29.23	19.408	78
TD	45.13	24.455	78
OP	23.14	18.848	78
EF	43.59	23.602	78
FR	27.18	21.691	78
CR	92.19	38.941	78
CC	13.41	9.903	78
IW	18.5583	11.34361	78
DRW	.3095	1.19583	78
TwoDPIF	.46	.502	78
ThrDPIF	.15	.363	78
SES2D	.19	.397	78
SES3D	.58	.497	78
CSP2D	.62	.490	78
CSP3D	.38	.490	78
MEP2D	.15	.363	78
MEP3D	.77	.424	78
CFQ2D	.42	.497	78
CFQ3D	.58	.497	78
MC	.27	.446	78
Time	10.6562	3.69491	78

Comp	34.6177	15.76106	78
DW	77.1004	15.05099	78

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	DW, SES2D, CHrs, CSP3D, Gender, ThrD, ThrDPIF, Seq5, MC, FR, Seq4, Seq1, TwoD, CR, PD, Ref, TD, DRW, CFQ2D, OP, MEP2D, Time, Age, Seq3, EF, TwoDPIF, CC, MD, IW, CAD, SES3D, MEP3D, Seq2, Exp, Comp[b]	.	Enter

a. Dependent Variable: RW

b. Tolerance = .000 limits reached.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000[a]	1.000	1.000	.11889

a. Predictors: (Constant), DW, SES2D, CHrs, CSP3D, Gender, ThrD, ThrDPIF, Seq5, MC, FR, Seq4, Seq1, TwoD, CR, PD, Ref, TD, DRW, CFQ2D, OP, MEP2D, Time, Age, Seq3, EF, TwoDPIF, CC, MD, IW, CAD, SES3D, MEP3D, Seq2, Exp, Comp

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	4448.493	35	127.100	8992.618	.000[b]
	Residual	.594	42	.014		
	Total	4449.086	77			

a. Dependent Variable: RW

b. Predictors: (Constant), DW, SES2D, CHrs, CSP3D, Gender, ThrD, ThrDPIF, Seq5, MC, FR, Seq4, Seq1, TwoD, CR, PD, Ref, TD, DRW, CFQ2D, OP, MEP2D, Time, Age, Seq3, EF, TwoDPIF, CC, MD, IW, CAD, SES3D, MEP3D, Seq2, Exp, Comp

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	99.906	.428		233.290	.000
	Age	.006	.007	.009	.918	.364
	Gender	.619	.178	.022	3.468	.001
	Exp	-.001	.007	-.001	-.091	.928
	Ref	.021	.016	.007	1.287	.205
	CHrs	.001	.001	.010	1.410	.166
	CAD	-.207	.098	-.013	-2.121	.040
	TwoD	.064	.041	.004	1.566	.125
	ThrD	.029	.042	.002	.684	.498
	Seq1	-.109	.129	-.005	-.845	.403
	Seq2	.023	.166	.001	.141	.888
	Seq3	.283	.100	.015	2.824	.007
	Seq4	.267	.113	.011	2.358	.023
	Seq5	.181	.062	.009	2.915	.006
	MD	.003	.003	.008	.878	.385
	PD	-.003	.003	-.007	-.735	.466
	TD	.000	.003	-.001	-.066	.948
	OP	.003	.003	.008	1.125	.267
	EF	-.002	.003	-.005	-.487	.629
	FR	.004	.003	.011	1.124	.267
	CR	-.001	.001	-.007	-2.047	.047
	CC	.007	.004	.009	1.717	.093
	IW	-1.004	.003	-1.498	-315.397	.000
	DRW	-1.125	.021	-.177	-54.768	.000
	TwoDPIF	.076	.093	.005	.818	.418
	ThrDPIF	.250	.082	.012	3.063	.004
	SES2D	.345	.140	.018	2.475	.017
	SES3D	.002	.080	.000	.025	.980
	CSP3D	-.060	.075	-.004	-.802	.427
	MEP2D	-.040	.127	-.002	-.315	.754
	MEP3D	.183	.112	.010	1.631	.110
	CFQ2D	-.037	.049	-.002	-.748	.459

	MC	.037	.075	.002	.492	.625
	Time	-.023	.008	-.011	-2.896	.006
	Comp	-.002	.018	-.003	-.089	.930
	DW	-1.005	.003	-1.991	-308.149	.000

a. Dependent Variable: RW

Excluded Variables[a]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	CSP2D	.[b]	.	.	.	.000
	CFQ3D	.[b]	.	.	.	.000

a. Dependent Variable: RW

b. Predictors in the Model: (Constant), DW, SES2D, CHrs, CSP3D, Gender, ThrD, ThrDPIF, Seq5, MC, FR, Seq4, Seq1, TwoD, CR, PD, Ref, TD, DRW, CFQ2D, OP, MEP2D, Time, Age, Seq3, EF, TwoDPIF, CC, MD, IW, CAD, SES3D, MEP3D, Seq2, Exp, Comp

VIFs and Reduced Model, Rework Rate, Practitioners Only

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	99.809	.424		235.440	.000		
	Age	.006	.007	.009	.918	.364	.034	29.024
	Gender	.619	.178	.022	3.468	.001	.080	12.477
	Exp	-.001	.007	-.001	-.091	.928	.029	34.005
	Ref	.021	.016	.007	1.287	.205	.123	8.120
	CHrs	.001	.001	.010	1.410	.166	.059	16.893
	CAD	-.207	.098	-.013	-2.121	.040	.084	11.879
	TwoD	.064	.041	.004	1.566	.125	.491	2.036
	ThrD	.029	.042	.002	.684	.498	.457	2.186
	Time	-.023	.008	-.011	-2.896	.006	.206	4.859
	Seq1	-.109	.129	-.005	-.845	.403	.107	9.382
	Seq2	.023	.166	.001	.141	.888	.042	23.560
	Seq3	.283	.100	.015	2.824	.007	.116	8.612
	Seq4	.267	.113	.011	2.358	.023	.138	7.236
	Seq5	.181	.062	.009	2.915	.006	.302	3.308
	Comp	-.002	.018	-.003	-.089	.930	.002	424.130
	MD	.003	.003	.008	.878	.385	.035	28.352
	PD	-.003	.003	-.007	-.735	.466	.040	24.741
	TD	.000	.003	-.001	-.066	.948	.029	33.982
	OP	.003	.003	.008	1.125	.267	.063	15.856
	EF	-.002	.003	-.005	-.487	.629	.031	32.404
	FR	.004	.003	.011	1.124	.267	.035	28.183
	CR	-.002	.001	-.007	-2.047	.047	.287	3.488
	CC	.003	.002	.009	1.717	.093	.127	7.891
	DW	-1.005	.003	-1.991	-308.149	.000	.076	13.139
	IW	-1.004	.003	-1.498	-315.397	.000	.141	7.104
	DRW	-1.125	.021	-.177	-54.768	.000	.304	3.285
	TwoDPIF	.076	.093	.005	.818	.418	.084	11.872
	ThrDPIF	.250	.082	.012	3.063	.004	.208	4.802

	SES2D	.345	.140	.018	2.475	.017	.060	16.699
	SES3D	.002	.080	.000	.025	.980	.115	8.663
	CSP2D	.060	.075	.004	.802	.427	.136	7.374
	MEP2D	-.040	.127	-.002	-.315	.754	.086	11.634
	MEP3D	.183	.112	.010	1.631	.110	.081	12.377
	CFQ3D	.037	.049	.002	.748	.459	.306	3.269
	MC	.037	.075	.002	.492	.625	.162	6.165

a. Dependent Variable: RW

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	MC, ThrD, ThrDPIF, Seq5, IW, CFQ3D, Seq4, Seq1, Ref, DRW, CR, TwoD, CSP2D, Seq3, SES3D, Time, CC[b]	.	Enter

a. Dependent Variable: RW

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.736[a]	.542	.412	5.82984

a. Predictors: (Constant), MC, ThrD, ThrDPIF, Seq5, IW, CFQ3D, Seq4, Seq1, Ref, DRW, CR, TwoD, CSP2D, Seq3, SES3D, Time, CC

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2409.863	17	141.757	4.171	.000[b]
	Residual	2039.223	60	33.987		
	Total	4449.086	77			

a. Dependent Variable: RW

b. Predictors: (Constant), MC, ThrD, ThrDPIF, Seq5, IW, CFQ3D, Seq4, Seq1, Ref, DRW, CR, TwoD, CSP2D, Seq3, SES3D, Time, CC

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	5.475	5.352		1.023	.310		
	Ref	-.719	.330	-.224	-2.180	.033	.726	1.377
	TwoD	1.941	1.772	.121	1.095	.278	.624	1.602
	ThrD	-.895	1.726	-.056	-.519	.606	.658	1.519
	Time	.782	.276	.380	2.830	.006	.423	2.364
	Seq1	-1.741	2.851	-.074	-.611	.544	.525	1.904
	Seq3	2.120	2.350	.111	.902	.371	.508	1.968
	Seq4	-2.841	2.586	-.120	-1.098	.276	.638	1.567
	Seq5	1.761	2.015	.092	.874	.386	.691	1.448
	CR	-.001	.038	-.004	-.037	.971	.516	1.937
	CC	.008	.057	.024	.137	.892	.246	4.071
	IW	-.132	.073	-.198	-1.813	.075	.644	1.554
	DRW	2.177	.732	.342	2.975	.004	.576	1.735
	ThrDPIF	-.651	2.283	-.031	-.285	.777	.642	1.557
	SES3D	-1.171	1.845	-.077	-.635	.528	.525	1.906
	CSP2D	-.410	1.819	-.026	-.225	.822	.556	1.798
	CFQ3D	-3.694	1.861	-.242	-1.985	.052	.516	1.939
	MC	-.251	2.416	-.015	-.104	.918	.379	2.636

a. Dependent Variable: RW

Appendix M: SPSS Multiple Regression Output, Students Only

Time to Completion as Dependent Variable

Descriptive Statistics

	Mean	Std. Deviation	N
Time	9.7321	2.05823	33
Age	28.45	5.221	33
Gender	.18	.392	33
Exp	2.6291	3.60089	33
Ref	5.36	2.848	33
CHrs	93.27	62.166	33
CAD	.91	.292	33
TwoD	.33	.479	33
ThrD	.33	.479	33
Seq1	.18	.392	33
Seq2	.18	.392	33
Seq3	.00	.000	33
Seq4	.27	.452	33
Seq5	.18	.392	33
Comp	28.8645	14.76234	33
MD	28.18	19.836	33
PD	24.24	16.636	33
TD	45.15	26.560	33
OP	17.58	15.768	33
EF	32.27	23.018	33
FR	25.76	23.356	33
CR	110.06	30.050	33
CC	20.30	9.174	33
DW	78.3961	12.08943	33
IW	17.1927	9.50191	33
RW	3.9609	5.41662	33
DRW	.4494	1.53919	33
TwoDPIF	.27	.452	33
ThrDPIF	.27	.452	33
SES2D	.18	.392	33
SES3D	.64	.489	33
CSP2D	.45	.506	33
CSP3D	.55	.506	33
MEP2D	.09	.292	33
MEP3D	.73	.452	33

CFQ2D	.36	.489	33
CFQ3D	.64	.489	33
MC	.09	.292	33

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	MC, ThrD, Ref, CR, DRW, CFQ3D, Seq1, IW, OP, Seq5, Gender, TwoD, PD, FR, RW, SES2D, CAD, MD, TD, CHrs, EF, ThrDPIF, CC[b]	.	Enter

a. Dependent Variable: Time

b. Tolerance = .000 limits reached.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.965[a]	.931	.754	1.02101

a. Predictors: (Constant), MC, ThrD, Ref, CR, DRW, CFQ3D, Seq1, IW, OP, Seq5, Gender, TwoD, PD, FR, RW, SES2D, CAD, MD, TD, CHrs, EF, ThrDPIF, CC

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	126.180	23	5.486	5.263	.007[b]
	Residual	9.382	9	1.042		
	Total	135.562	32			

a. Dependent Variable: Time

b. Predictors: (Constant), MC, ThrD, Ref, CR, DRW, CFQ3D, Seq1, IW, OP, Seq5, Gender, TwoD, PD, FR, RW, SES2D, CAD, MD, TD, CHrs, EF, ThrDPIF, CC

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	13.631	3.221		4.232	.002
	Gender	-10.665	3.573	-2.029	-2.985	.015
	Ref	-1.154	.467	-1.596	-2.471	.036
	CHrs	-.003	.010	-.096	-.333	.747
	CAD	7.562	3.050	1.073	2.479	.035
	TwoD	.844	.809	.196	1.043	.324
	ThrD	.743	.739	.173	1.006	.341
	Seq1	5.963	2.892	1.135	2.062	.069
	Seq5	1.769	1.040	.337	1.702	.123
	MD	.028	.044	.266	.628	.546
	PD	-.003	.021	-.023	-.140	.892
	TD	.008	.020	.100	.388	.707
	OP	.054	.023	.413	2.301	.047
	EF	-.032	.042	-.358	-.771	.461
	FR	.010	.024	.110	.404	.696
	CR	-.154	.071	-2.255	-2.172	.058
	CC	.556	.286	2.479	1.948	.083
	IW	.048	.031	.222	1.554	.155
	RW	.109	.072	.286	1.510	.165
	DRW	-.258	.352	-.193	-.732	.483
	ThrDPIF	-1.174	2.162	-.258	-.543	.600
	SES2D	-.226	1.043	-.043	-.217	.833
	CFQ3D	-1.487	1.201	-.353	-1.238	.247
	MC	4.070	2.788	.577	1.460	.178

a. Dependent Variable: Time

Excluded Variables[a]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	Age	.[b]	.	.	.	.000
	Exp	.[b]	.	.	.	.000
	Seq2	.[b]	.	.	.	.000
	Seq4	.[b]	.	.	.	.000
	Comp	707.221[b]	.804	.445	.273	1.034E-008
	DW	-113.112[b]	-.239	.817	-.084	3.836E-008
	TwoDPIF	.[b]	.	.	.	.000
	SES3D	.[b]	.	.	.	.000
	CSP2D	.[b]	.	.	.	.000
	CSP3D	.[b]	.	.	.	.000
	MEP2D	.[b]	.	.	.	.000
	MEP3D	.[b]	.	.	.	.000
	CFQ2D	.[b]	.	.	.	.000

a. Dependent Variable: Time

b. Predictors in the Model: (Constant), MC, ThrD, Ref, CR, DRW, CFQ3D, Seq1, IW, OP, Seq5, Gender, TwoD, PD, FR, RW, SES2D, CAD, MD, TD, CHrs, EF, ThrDPIF, CC

VIFs and Reduced Model, Time to Completion, Students Only

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	13.631	3.221		4.232	.002		
	Gender	-10.665	3.573	-2.029	-2.985	.015	.017	60.129
	Ref	-1.154	.467	-1.596	-2.471	.036	.018	54.285
	CHrs	-.003	.010	-.096	-.333	.747	.092	10.873
	CAD	7.562	3.050	1.073	2.479	.035	.041	24.342
	TwoD	.844	.809	.196	1.043	.324	.217	4.603
	ThrD	.743	.739	.173	1.006	.341	.260	3.841
	Seq1	5.963	2.892	1.135	2.062	.069	.025	39.398
	Seq5	1.769	1.040	.337	1.702	.123	.196	5.092
	MD	.028	.044	.266	.628	.546	.043	23.319
	PD	-.003	.021	-.023	-.140	.892	.273	3.661
	TD	.008	.020	.100	.388	.707	.115	8.685
	OP	.054	.023	.413	2.301	.047	.239	4.184
	EF	-.032	.042	-.358	-.771	.461	.036	28.103
	FR	.010	.024	.110	.404	.696	.104	9.582
	CR	-.247	.114	-2.255	-2.172	.058	.007	140.203
	CC	.234	.120	2.479	1.948	.083	.005	210.625
	IW	.048	.031	.222	1.554	.155	.376	2.661
	RW	.109	.072	.286	1.510	.165	.214	4.670
	DRW	-.258	.352	-.193	-.732	.483	.111	9.036
	ThrDPIF	-1.174	2.162	-.258	-.543	.600	.034	29.352
	SES2D	-.226	1.043	-.043	-.217	.833	.195	5.121
	CFQ3D	-1.487	1.201	-.353	-1.238	.247	.095	10.562
	MC	4.070	2.788	.577	1.460	.178	.049	20.337

a. Dependent Variable: Time

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	DRW, OP, ThrD, Seq4, IW, TD, PD, TwoD, RW[b]	.	Enter

a. Dependent Variable: Time

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.777[a]	.604	.449	1.52842

a. Predictors: (Constant), DRW, OP, ThrD, Seq4, IW, TD, PD, TwoD, RW

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	81.832	9	9.092	3.892	.004[b]
	Residual	53.730	23	2.336		
	Total	135.562	32			

a. Dependent Variable: Time

b. Predictors: (Constant), DRW, OP, ThrD, Seq4, IW, TD, PD, TwoD, RW

Coefficients^{a}

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	7.928	.967		8.195	.000		
	TwoD	.100	.753	.023	.132	.896	.561	1.782
	ThrD	-.398	.669	-.092	-.595	.558	.712	1.404
	Seq4	-.108	.677	-.024	-.159	.875	.779	1.284
	PD	.024	.019	.196	1.285	.212	.738	1.354
	TD	-.017	.011	-.217	-1.539	.137	.869	1.151
	OP	.018	.019	.141	.976	.339	.825	1.213
	IW	.066	.031	.305	2.119	.045	.831	1.203
	RW	.121	.072	.317	1.682	.106	.484	2.066
	DRW	.367	.277	.275	1.326	.198	.402	2.487

a. Dependent Variable: Time

Composite Workload as Dependent Variable

Descriptive Statistics

	Mean	Std. Deviation	N
Comp	28.8645	14.76234	33
Age	28.45	5.221	33
Gender	.18	.392	33
Exp	2.6291	3.60089	33
Ref	5.36	2.848	33
CHrs	93.27	62.166	33
CAD	.91	.292	33
TwoD	.33	.479	33
ThrD	.33	.479	33
Seq1	.18	.392	33
Seq2	.18	.392	33
Seq3	.00	.000	33
Seq4	.27	.452	33
Seq5	.18	.392	33
MD	28.18	19.836	33
PD	24.24	16.636	33
TD	45.15	26.560	33
OP	17.58	15.768	33
EF	32.27	23.018	33
FR	25.76	23.356	33
CR	110.06	30.050	33
CC	20.30	9.174	33
DW	78.3961	12.08943	33
IW	17.1927	9.50191	33
RW	3.9609	5.41662	33
DRW	.4494	1.53919	33
TwoDPIF	.27	.452	33
ThrDPIF	.27	.452	33
SES2D	.18	.392	33
SES3D	.64	.489	33
CSP2D	.45	.506	33
CSP3D	.55	.506	33
MEP2D	.09	.292	33
MEP3D	.73	.452	33
CFQ2D	.36	.489	33

CFQ3D	.64	.489	33
MC	.09	.292	33
Time	9.7321	2.05823	33

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Time, FR, CSP3D, TwoD, Age, ThrDPIF, Seq5, TD, MC, ThrD, RW, OP, SES2D, CR, IW, PD, Seq1, DRW, MEP3D, MD, Gender, EF, Ref, CC[b]	.	Enter

a. Dependent Variable: Comp

b. Tolerance = .000 limits reached.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000[a]	1.000	1.000	.00289

a. Predictors: (Constant), Time, FR, CSP3D, TwoD, Age, ThrDPIF, Seq5, TD, MC, ThrD, RW, OP, SES2D, CR, IW, PD, Seq1, DRW, MEP3D, MD, Gender, EF, Ref, CC

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	6973.649	24	290.569	34828992.397	.000[b]
	Residual	.000	8	.000		
	Total	6973.649	32			

a. Dependent Variable: Comp

b. Predictors: (Constant), Time, FR, CSP3D, TwoD, Age, ThrDPIF, Seq5, TD, MC, ThrD, RW, OP, SES2D, CR, IW, PD, Seq1, DRW, MEP3D, MD, Gender, EF, Ref, CC

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-.011	.021		-.551	.597
	Age	.000	.000	.000	.742	.479
	Gender	.016	.018	.000	.924	.383
	Ref	.003	.003	.001	.921	.384
	TwoD	.001	.002	.000	.222	.830
	ThrD	-.001	.002	.000	-.370	.721
	Seq1	-.014	.013	.000	-1.088	.308
	Seq5	-.005	.008	.000	-.622	.551
	MD	.167	.000	.224	1313.300	.000
	PD	.167	.000	.188	2834.763	.000
	TD	.167	.000	.300	2917.331	.000
	OP	.167	.000	.178	1997.267	.000
	EF	.167	.000	.260	1371.739	.000
	FR	.167	.000	.264	2440.440	.000
	CR	9.235E-005	.000	.000	.372	.720
	CC	-.001	.001	.000	-.666	.524
	IW	.000	.000	.000	-2.464	.039
	RW	.000	.000	.000	-1.501	.172
	DRW	.001	.001	.000	.824	.434
	ThrDPIF	.005	.009	.000	.623	.551
	SES2D	-.015	.007	.000	-2.011	.079
	CSP3D	.004	.006	.000	.670	.522
	MEP3D	-.011	.007	.000	-1.660	.135
	MC	-.018	.015	.000	-1.172	.275
	Time	.001	.001	.000	.804	.445

a. Dependent Variable: Comp

Excluded Variables[a]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	Exp	.[b]	.	.	.	.000
	CHrs	.[b]	.	.	.	.000
	CAD	.[b]	.	.	.	.000
	Seq2	.[b]	.	.	.	.000
	Seq4	.[b]	.	.	.	.000
	DW	-.184[b]	-1.044	.331	-.367	3.809E-008
	TwoDPIF	.[b]	.	.	.	.000
	SES3D	.[b]	.	.	.	.000
	CSP2D	.[b]	.	.	.	.000
	MEP2D	.[b]	.	.	.	.000
	CFQ2D	.[b]	.	.	.	.000
	CFQ3D	.[b]	.	.	.	.000

a. Dependent Variable: Comp

b. Predictors in the Model: (Constant), Time, FR, CSP3D, TwoD, Age, ThrDPIF, Seq5, TD, MC, ThrD, RW, OP, SES2D, CR, IW, PD, Seq1, DRW, MEP3D, MD, Gender, EF, Ref, CC

VIFs and Reduced Model, Composite Workload, Students Only

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	-.002	.016		-.100	.923		
	Gender	.013	.014	.000	.897	.396	.008	119.638
	Ref	.001	.002	.000	.584	.575	.011	91.108
	CHrs	5.652E-005	.000	.000	2.074	.072	.091	11.008
	CAD	-.012	.011	.000	-1.104	.302	.024	40.965
	TwoD	.001	.002	.000	.222	.830	.194	5.159
	ThrD	-.001	.002	.000	-.370	.721	.234	4.273
	Time	.001	.001	.000	.804	.445	.069	14.449
	Seq1	-.005	.010	.000	-.543	.602	.017	58.004
	Seq5	.002	.003	.000	.606	.561	.149	6.730
	MD	.167	.000	.224	1313.300	.000	.041	24.341
	PD	.167	.000	.188	2834.763	.000	.273	3.669
	TD	.167	.000	.300	2917.331	.000	.113	8.830
	OP	.167	.000	.178	1997.267	.000	.150	6.646
	EF	.167	.000	.260	1371.739	.000	.033	29.958
	FR	.167	.000	.264	2440.440	.000	.103	9.756
	CR	.000	.000	.000	.372	.720	.005	213.699
	CC	.000	.000	.000	-.666	.524	.003	299.424
	IW	.000	.000	.000	-2.464	.039	.296	3.374
	RW	.000	.000	.000	-1.501	.172	.171	5.853
	DRW	.001	.001	.000	.824	.434	.104	9.574
	ThrDPIF	.001	.006	.000	.099	.924	.033	30.314
	SES2D	-.001	.003	.000	-.292	.778	.194	5.148
	CFQ3D	.006	.004	.000	1.622	.144	.081	12.361
	MC	-.009	.009	.000	-.985	.354	.040	25.153

a. Dependent Variable: Comp

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	MC, ThrD, TD, IW, RW, PD, OP, TwoD, DRW, Time[b]	.	Enter

a. Dependent Variable: Comp

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.831[a]	.691	.551	9.89380

a. Predictors: (Constant), MC, ThrD, TD, IW, RW, PD, OP, TwoD, DRW, Time

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	4820.127	10	482.013	4.924	.001[b]
	Residual	2153.522	22	97.887		
	Total	6973.649	32			

a. Dependent Variable: Comp

b. Predictors: (Constant), MC, ThrD, TD, IW, RW, PD, OP, TwoD, DRW, Time

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	7.674	12.360		.621	.541		
	TwoD	-2.228	4.879	-.072	-.457	.652	.561	1.783
	ThrD	-4.643	4.364	-.151	-1.064	.299	.701	1.427
	Time	-.521	1.351	-.073	-.386	.703	.396	2.527
	PD	.363	.125	.409	2.906	.008	.708	1.413
	TD	.236	.073	.425	3.220	.004	.805	1.242
	OP	.382	.127	.408	3.012	.006	.767	1.304
	IW	.146	.221	.094	.661	.516	.695	1.438
	RW	.103	.486	.038	.212	.834	.442	2.261
	DRW	-.531	1.791	-.055	-.297	.770	.402	2.485
	MC	-3.348	6.776	-.066	-.494	.626	.782	1.279

a. Dependent Variable: Comp

Direct Work Rate as Dependent Variable

Descriptive Statistics

	Mean	Std. Deviation	N
DW	78.3961	12.08943	33
Age	28.45	5.221	33
Gender	.18	.392	33
Exp	2.6291	3.60089	33
Ref	5.36	2.848	33
CHrs	93.27	62.166	33
CAD	.91	.292	33
TwoD	.33	.479	33
ThrD	.33	.479	33
Seq1	.18	.392	33
Seq2	.18	.392	33
Seq3	.00	.000	33
Seq4	.27	.452	33
Seq5	.18	.392	33
MD	28.18	19.836	33
PD	24.24	16.636	33
TD	45.15	26.560	33
OP	17.58	15.768	33
EF	32.27	23.018	33
FR	25.76	23.356	33
CR	110.06	30.050	33
CC	20.30	9.174	33
IW	17.1927	9.50191	33
RW	3.9609	5.41662	33
DRW	.4494	1.53919	33
TwoDPIF	.27	.452	33
ThrDPIF	.27	.452	33
SES2D	.18	.392	33
SES3D	.64	.489	33
CSP2D	.45	.506	33
CSP3D	.55	.506	33
MEP2D	.09	.292	33
MEP3D	.73	.452	33
CFQ2D	.36	.489	33
CFQ3D	.64	.489	33
MC	.09	.292	33

Time	9.7321	2.05823	33
Comp	28.8645	14.76234	33

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Comp, RW, CSP3D, IW, Exp, TwoD, Seq5, CC, ThrD, Age, SES3D, Gender, PD, CHrs, OP, DRW, MEP3D, Time, TD, FR, MC, CAD, MD, CR[b]	.	Enter

a. Dependent Variable: DW

b. Tolerance = .000 limits reached.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000[a]	1.000	1.000	.00472

a. Predictors: (Constant), Comp, RW, CSP3D, IW, Exp, TwoD, Seq5, CC, ThrD, Age, SES3D, Gender, PD, CHrs, OP, DRW, MEP3D, Time, TD, FR, MC, CAD, MD, CR

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	4676.940	24	194.873	8747610.677	.000[b]
	Residual	.000	8	.000		
	Total	4676.941	32			

a. Dependent Variable: DW

b. Predictors: (Constant), Comp, RW, CSP3D, IW, Exp, TwoD, Seq5, CC, ThrD, Age, SES3D, Gender, PD, CHrs, OP, DRW, MEP3D, Time, TD, FR, MC, CAD, MD, CR

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	99.996	.015		6524.120	.000
	Age	.001	.001	.000	.782	.457
	Gender	-.012	.017	.000	-.718	.493
	Exp	-.003	.002	-.001	-1.058	.321
	CHrs	-7.619E-005	.000	.000	-.481	.644
	CAD	.013	.033	.000	.380	.714
	TwoD	.000	.004	.000	.028	.979
	ThrD	.002	.004	.000	.528	.612
	Seq5	-.004	.006	.000	-.666	.524
	MD	.000	.000	-.001	-.957	.366
	PD	-7.010E-005	.000	.000	-.320	.757
	TD	.000	.000	.000	-.566	.587
	OP	.000	.000	.000	-1.061	.320
	FR	.000	.000	.000	-.480	.644
	CR	.000	.000	-.001	-.815	.438
	CC	.001	.002	.001	.871	.409
	IW	-1.000	.000	-.786	-6198.139	.000
	RW	-1.000	.000	-.448	-2681.489	.000
	DRW	-1.001	.002	-.127	-596.821	.000
	SES3D	-.005	.010	.000	-.513	.622
	CSP3D	-.007	.014	.000	-.469	.652
	MEP3D	-.009	.019	.000	-.473	.649
	MC	-.005	.016	.000	-.337	.745
	Time	.000	.002	.000	-.240	.816
	Comp	.001	.001	.001	.847	.422

a. Dependent Variable: DW

Excluded Variables[a]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	Ref	.[b]	.	.	.	.000
	Seq1	.[b]	.	.	.	.000
	Seq2	.[b]	.	.	.	.000
	Seq4	.[b]	.	.	.	.000
	EF	.190[b]	1.046	.330	.368	1.419E-007
	TwoDPIF	.[b]	.	.	.	.000
	ThrDPIF	.[b]	.	.	.	.000
	SES2D	.[b]	.	.	.	.000
	CSP2D	.[b]	.	.	.	.000
	MEP2D	.[b]	.	.	.	.000
	CFQ2D	.[b]	.	.	.	.000
	CFQ3D	.[b]	.	.	.	.000

a. Dependent Variable: DW

b. Predictors in the Model: (Constant), Comp, RW, CSP3D, IW, Exp, TwoD, Seq5, CC, ThrD, Age, SES3D, Gender, PD, CHrs, OP, DRW, MEP3D, Time, TD, FR, MC, CAD, MD, CR

VIFs and Reduced Model, Direct Work Rate, Students Only

Coefficients^{a}

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	100.012	.026		3885.384	.000		
	Gender	-.017	.023	-.001	-.741	.480	.008	119.638
	Ref	-.002	.003	.000	-.709	.498	.011	91.108
	CHrs	-6.475E-006	.000	.000	-.145	.888	.091	11.008
	CAD	.003	.018	.000	.191	.853	.024	40.965
	TwoD	.000	.004	.000	.028	.978	.194	5.159
	ThrD	.002	.004	.000	.528	.612	.234	4.273
	Time	.000	.002	.000	-.239	.817	.069	14.449
	Seq1	.019	.016	.001	1.170	.276	.017	58.004
	Seq5	.004	.006	.000	.722	.491	.149	6.730
	MD	.000	.000	.000	-.937	.376	.041	24.341
	PD	9.799E-005	.000	.000	1.020	.337	.273	3.669
	TD	4.717E-005	.000	.000	.505	.627	.113	8.830
	OP	.000	.000	.000	-1.066	.317	.150	6.646
	EF	.000	.000	.000	.849	.421	.033	29.958
	FR	5.796E-005	.000	.000	.520	.617	.103	9.756
	CR	-.001	.001	-.001	-.816	.438	.005	213.699
	CC	.001	.001	.001	.872	.409	.003	299.424
	IW	-1.000	.000	-.786	-6199.287	.000	.296	3.374
	RW	-1.000	.000	-.448	-2683.166	.000	.171	5.853
	DRW	-1.001	.002	-.127	-597.033	.000	.104	9.574
	ThrDPIF	-.005	.010	.000	-.460	.657	.033	30.314
	SES2D	.002	.005	.000	.416	.689	.194	5.148
	CFQ3D	-.005	.006	.000	-.787	.454	.081	12.361
	MC	.010	.014	.000	.700	.504	.040	25.153

a. Dependent Variable: DW

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	MC, ThrD, DRW, IW, Seq4, TwoD, Time, RW[b]	.	Enter

a. Dependent Variable: DW

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000[a]	1.000	1.000	.00364

a. Predictors: (Constant), MC, ThrD, DRW, IW, Seq4, TwoD, Time, RW

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	4676.940	8	584.618	44132348.344	.000[b]
	Residual	.000	24	.000		
	Total	4676.941	32			

a. Dependent Variable: DW

b. Predictors: (Constant), MC, ThrD, DRW, IW, Seq4, TwoD, Time, RW

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	100.001	.004		25645.874	.000		
	TwoD	-.003	.002	.000	-1.523	.141	.557	1.795
	ThrD	-.001	.002	.000	-.574	.572	.716	1.397
	Time	-.001	.000	.000	-1.169	.254	.470	2.125
	Seq4	.001	.002	.000	.708	.486	.672	1.488
	IW	-1.000	.000	-.786	-12419.442	.000	.708	1.413
	RW	-1.000	.000	-.448	-5577.054	.000	.439	2.278
	DRW	-1.000	.001	-.127	-1515.321	.000	.401	2.494
	MC	-.003	.003	.000	-1.085	.289	.676	1.480

a. Dependent Variable: DW

Rework Rate as Dependent Variable

Descriptive Statistics

	Mean	Std. Deviation	N
RW	3.9609	5.41662	33
Age	28.45	5.221	33
Gender	.18	.392	33
Exp	2.6291	3.60089	33
Ref	5.36	2.848	33
CHrs	93.27	62.166	33
CAD	.91	.292	33
TwoD	.33	.479	33
ThrD	.33	.479	33
Seq1	.18	.392	33
Seq2	.18	.392	33
Seq3	.00	.000	33
Seq4	.27	.452	33
Seq5	.18	.392	33
MD	28.18	19.836	33
PD	24.24	16.636	33
TD	45.15	26.560	33
OP	17.58	15.768	33
EF	32.27	23.018	33
FR	25.76	23.356	33
CR	110.06	30.050	33
CC	20.30	9.174	33
IW	17.1927	9.50191	33
DRW	.4494	1.53919	33
TwoDPIF	.27	.452	33
ThrDPIF	.27	.452	33
SES2D	.18	.392	33
SES3D	.64	.489	33
CSP2D	.45	.506	33
CSP3D	.55	.506	33
MEP2D	.09	.292	33
MEP3D	.73	.452	33
CFQ2D	.36	.489	33
CFQ3D	.64	.489	33
MC	.09	.292	33

Time	9.7321	2.05823	33
Comp	28.8645	14.76234	33
DW	78.3961	12.08943	33

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	DW, Seq5, Age, TD, TwoD, MC, Seq2, ThrDPIF, ThrD, OP, FR, PD, SES2D, DRW, CSP3D, CR, Time, Seq1, IW, MD, Ref, EF, CC, Seq4[b]	.	Enter

a. Dependent Variable: RW

b. Tolerance = .000 limits reached.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000[a]	1.000	1.000	.00472

a. Predictors: (Constant), DW, Seq5, Age, TD, TwoD, MC, Seq2, ThrDPIF, ThrD, OP, FR, PD, SES2D, DRW, CSP3D, CR, Time, Seq1, IW, MD, Ref, EF, CC, Seq4

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	938.873	24	39.120	1755689.773	.000[b]
	Residual	.000	8	.000		
	Total	938.873	32			

a. Dependent Variable: RW

b. Predictors: (Constant), DW, Seq5, Age, TD, TwoD, MC, Seq2, ThrDPIF, ThrD, OP, FR, PD, SES2D, DRW, CSP3D, CR, Time, Seq1, IW, MD, Ref, EF, CC, Seq4

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	99.997	.040		2476.074	.000
	Age	.001	.003	.001	.494	.634
	Ref	-.001	.003	-.001	-.570	.584
	TwoD	.000	.004	.000	.028	.979
	ThrD	.002	.004	.000	.527	.613
	Seq1	.017	.016	.001	1.077	.313
	Seq2	.003	.015	.000	.236	.820
	Seq4	.020	.032	.002	.618	.554
	Seq5	.014	.023	.001	.607	.560
	MD	.000	.000	-.001	-.936	.377
	PD	9.806E-005	.000	.000	1.021	.337
	TD	4.715E-005	.000	.000	.505	.627
	OP	.000	.000	.000	-1.066	.317
	EF	.000	.000	.001	.848	.421
	FR	5.792E-005	.000	.000	.519	.618
	CR	.000	.000	-.002	-.814	.439
	CC	.001	.002	.002	.870	.410
	IW	-1.000	.000	-1.754	-3025.624	.000
	DRW	-1.001	.002	-.285	-508.283	.000
	ThrDPIF	.002	.008	.000	.235	.820
	SES2D	.009	.009	.001	1.000	.347
	CSP3D	-.009	.020	-.001	-.478	.646
	MC	.008	.016	.000	.511	.623
	Time	.000	.002	.000	-.238	.818
	DW	-1.000	.000	-2.233	-2683.166	.000

a. Dependent Variable: RW

Excluded Variables[a]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	Gender	.[b]	.	.	.	.000
	Exp	.[b]	.	.	.	.000
	CHrs	.[b]	.	.	.	.000
	CAD	.[b]	.	.	.	.000
	TwoDPIF	.[b]	.	.	.	.000
	SES3D	.[b]	.	.	.	.000
	CSP2D	.[b]	.	.	.	.000
	MEP2D	.[b]	.	.	.	.000
	MEP3D	.[b]	.	.	.	.000
	CFQ2D	.[b]	.	.	.	.000
	CFQ3D	.[b]	.	.	.	.000
	Comp	-1.637[b]	-1.046	.331	-.368	9.575E-009

a. Dependent Variable: RW

b. Predictors in the Model: (Constant), DW, Seq5, Age, TD, TwoD, MC, Seq2, ThrDPIF, ThrD, OP, FR, PD, SES2D, DRW, CSP3D, CR, Time, Seq1, IW, MD, Ref, EF, CC, Seq4

VIFs and Reduced Model, Rework Rate, Students Only

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	100.045	.055		1811.596	.000		
	Gender	-.017	.023	-.001	-.738	.481	.008	119.682
	Ref	-.002	.003	-.001	-.707	.499	.011	91.135
	CHrs	-6.443E-006	.000	.000	-.145	.889	.091	11.008
	CAD	.003	.018	.000	.189	.855	.024	40.968
	TwoD	.000	.004	.000	.028	.979	.194	5.159
	ThrD	.002	.004	.000	.527	.613	.234	4.274
	Time	.000	.002	.000	-.238	.818	.069	14.450
	Seq1	.019	.016	.001	1.167	.277	.017	58.036
	Seq5	.004	.006	.000	.722	.491	.149	6.730
	MD	.000	.000	-.001	-.936	.377	.041	24.347
	PD	9.806E-005	.000	.000	1.021	.337	.273	3.668
	TD	4.715E-005	.000	.000	.505	.627	.113	8.831
	OP	.000	.000	.000	-1.066	.317	.150	6.645
	EF	.000	.000	.001	.848	.421	.033	29.965
	FR	5.792E-005	.000	.000	.519	.618	.102	9.756
	CR	-.001	.001	-.002	-.814	.439	.005	213.782
	CC	.001	.001	.002	.870	.410	.003	299.549
	DW	-1.000	.000	-2.233	-2683.166	.000	.034	29.174
	IW	-1.000	.000	-1.754	-3025.624	.000	.071	14.166
	DRW	-1.001	.002	-.285	-508.283	.000	.076	13.209
	ThrDPIF	-.005	.010	.000	-.460	.658	.033	30.315
	SES2D	.002	.005	.000	.416	.688	.194	5.148
	CFQ3D	-.005	.006	.000	-.785	.455	.081	12.365
	MC	.010	.014	.001	.698	.505	.040	25.160

a. Dependent Variable: RW

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	DRW, OP, ThrD, TD, IW, PD, TwoD, Time[b]	.	Enter

a. Dependent Variable: RW

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.745[a]	.555	.407	4.17176

a. Predictors: (Constant), DRW, OP, ThrD, TD, IW, PD, TwoD, Time

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	521.188	8	65.148	3.743	.006[b]
	Residual	417.685	24	17.404		
	Total	938.873	32			

a. Dependent Variable: RW

b. Predictors: (Constant), DRW, OP, ThrD, TD, IW, PD, TwoD, Time

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	-6.030	5.058		-1.192	.245		
	TwoD	3.437	1.929	.304	1.782	.087	.638	1.568
	ThrD	.770	1.832	.068	.420	.678	.707	1.415
	Time	.954	.534	.362	1.785	.087	.449	2.225
	PD	.011	.050	.034	.222	.826	.788	1.270
	TD	.017	.031	.085	.563	.579	.822	1.217
	OP	-.010	.052	-.029	-.193	.848	.806	1.241
	IW	-.142	.088	-.249	-1.611	.120	.775	1.291
	DRW	1.951	.641	.554	3.042	.006	.558	1.793

a. Dependent Variable: RW

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VITA

Gabriel Biratu Dadi was born to Biratu and Clara Dadi in Louisville, Kentucky. After graduating from St. Xavier High School in Louisville, he attended the University of Kentucky pursuing a Bachelor of Science degree in civil engineering, where he received several scholarships and awards to support his studies. Prior to graduation in 2007, he enrolled in the dual degree BS/MBA program at the University of Kentucky to expand his knowledge base as a Finnie Graduate Fellow and Beard Graduate Fellow. The graduate program culminated in 2008 with a study abroad session throughout Europe focusing on international business administration and economics. Upon return to the United States, he accepted a position as a project engineer for a construction management and general contracting firm in Lexington, Kentucky. After a few years working in industry, he decided to return to the University of Kentucky to begin scholastic activities towards a doctorate degree in civil engineering as a Walker Fellow. He has authored and co-authored several conference papers, technical reports, and journal papers. His research interests include information delivery strategies, additive manufacturing technologies, visualization of spatial engineering information, behavioral and cognitive studies of construction practitioners, and building information modeling for construction use.