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Synergy of the Developed 6D BIM Framework and Conception of the nD BIM Framework and nD BIM Process Ontology

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SYNERGY OF THE DEVELOPED 6D BIM FRAMEWORK AND CONCEPTION OF THE ND BIM FRAMEWORK AND ND BIM PROCESS ONTOLOGY

by

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Abstract of a Dissertation
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ABSTRACT

SYNERGY OF THE DEVELOPED 6D BIM FRAMEWORK AND

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The author developed a unified nD framework and process ontology for Building Information Modeling (BIM). The research includes a framework developed for 6D BIM, nD BIM, and nD ontology that defines the domain and sub-domain constructs for future nD BIM dimensions. The nD ontology defines the relationships of kinds within any new proposed dimensional domain for BIM. The developed nD BIM framework and ontology takes into account the current 2D-5D BIM dimensions. There is a synergy between the 6D and nD framework that allows the nD framework and ontology to be utilized as a unified template for future dimensional development. Future dimensions for BIM are referred as nD dimensions. The Architecture, Engineering, Construction, and Facility Management (AEC/FM) industries are suffering from many problems in the area of interoperability among BIM dimensions. All nD dimensions must be interoperable. The congestion between interoperable dimensions and communication among AEC/FM stakeholders are the main problems to be resolved. The objective of the research is to solve these problems by utilizing one single nD framework and ontology for nD BIMs. The AEC/FM industries can benefit from the developed 6D framework, nD framework and nD process ontology. nD dimensions must have ontological rules that clearly define

the new dimension. The AEC/FM needs non-abstract dimensions to succeed in the areas of seamless dimensional integration, interoperability, round tripping of dimensional data, and precise collaboration among stakeholders. Defined dimensions allow future dimensions to be implemented in an integrated workflow. nD ontology demonstrates new dimensional domain K' shall be defined while also explicitly defining its subset-domains {K1, K2…Kn}, and subset domains K shall contain some x information for interoperability among dimensions that are within K'. The research contributions are the framework and ontology for nD BIM. The author conducted case studies that validate the nD methodology. The case studies show that the methodology of the input, output, control and mechanism are correct and the theory can be utilized in application for the AEC/FM and is applicable for other industries. Other contributions include the custom web-based BimServer that serves as the central repository for harvesting all control data within nD BIMs and allows all stakeholders to participate on projects in real-time via an embedded virtual environment in the BimServer. The nD BIM methodology consists of one object-oriented parametric product data model as the input and the output. A relational database is the mechanism for the nD BIM process that distributes the dimensional data. The database is the crux of the nD BIM and it allows the interoperability between the nD dimensions and querying of the nD parametric product data.

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CHAPTER I

INTRODUCTION

Problem Statement

The AEC/FM industries are suffering from abstract dimensions in their daily practice. Stakeholders are having trouble handling the interoperability of new dimensional data and conversing about new dimensions when collaborating with each other. Currently one nD BIM that contains all necessary data for the whole building life cycle with a methodology for added future dimensions does not exist. Also a platform for harvesting all nD project data does not exist for nD BIMs. Web-based collaboration is a challenge for the AEC/FM and is an issue that must be resolved. The AEC/FM must recognize that their problems can be resolved by utilization of one schema for all object-oriented parametric product data. A single holistic database that links all dimensions in the BIM workflow are not the norm for the AEC/FM. All of these problems need to be resolved for these industries to prosper when using the BIM philosophy in daily practice. The AEC/FM need a simple solution to overcome these adversities.

Overview of Dissertation Work and Contribution

The objective of this doctoral dissertation is to go beyond the current practices of national and international industry views on BIM dimensions and into the depth of a possible future of the many new upcoming BIM dimensions, and beyond the current employment of current technology in the AEC/FM industries. A contribution of this research is the development of energy informatics as the sixth dimension for BIM by creating information models. The author has developed a synergistic process ontology and framework showing new rules the AEC/FM can utilize to create new nD BIM dimensions. Ghassan, Lee, and Wu (2007) speak of the future of the AEC/FM and explain nD dimensions must be clear in nature and function so all stakeholders involved are clear when conversing, collaborating, and sharing their legal information as data and documentations. In this doctoral dissertation, the author explains the vastly occurring BIM paradigm shift of the AEC/FM industries and the dynamic integrated approaches that accompany the dramatic change in practice. Discussed in great detail are the technologies needed to employ a new and efficient multi-dimensional integrated AEC/FM world. There are multiple dimensions in integrated AEC/FM practice. These dimensions are covered in Chapter II. The focus of Chapter III is the sixth dimension created by the author known as an energy dimension with informatics including subset-domains, e.g. acoustical particle and vector analysis, photo-voltaic building simulation, etc.

The feasibility of a sixth dimension blossomed due to research and testing the replication of results of BIM interoperability and testing among custom and proprietary systems. A developed nD BIM software application is utilized to show the implementation of the 6D and nD frameworks and the benefits they bring to the industry. A web-based virtual review system that utilizes an open source BIMserver and game engine technology is created to supplement the nD BIM application. The nD BIM software tool can integrate with any IFC BIM. A relational database distributes the IFC data to perform energy informatics analysis, e.g. Leadership in Energy and Environmental Design (LEED) quantification of cost and certification validation in a virtual environment and Construction Operations Information Exchange (COBie) Facility Management (FM) integration via IFC and relational database (East and Brodt 2007). The author also uses the Construction Specification's (CSI) Omniclass as a standard for classifying industry product, labor, and materials data via the database for all sectors of the AEC/FM industries. The development of the nD BIM software led to the conception of a framework for the sixth through nD dimensions. It was then noticed that nD ontology was feasible by research discussed in Chapter IV.

An objective of the research is to show that nD ontology, variable (nDo), can be used for all dimensional domains of K' and subset-domains K; therefore, K' implies K because of the heredity property of the information x, that can be the ontology information for nD. An ontology can be assumed to be x such that the x information in K' implies the x information in K are the same through heredity. Now dimensions 2D to nD can utilize x to minimize congestion among dimensional information exchange called interoperability if and only if x2 contains the inherited information from previous x1. The message exchange when blocked and non-blocking of bits during the hereditary property is the control for the integrity of information x of X size.

For some x information to maintain integrity and system compliance during interoperability among dimensions in software systems, all x's must be bounded by the framework utilized in all nD's. Therefore, all x's can be synonymous in any domain of nD, K', and K. This does not imply x's must be relational in a semantic nature. In the future semantic design complexity will not be optimal to compute because of large amounts redundant data relational system contains. Walfish, Balakrishnan, and Shenker (2004) write of semantic free reference (SFR) to untangle the web from domain name systems (DNS). The SFR may be another rout in the future. By applying the idea of SFR in regards to information x so we can do more with less due to the nature of an x with no semantic attachment. In this case, x needs a multi-agent (Rahimi and Carver 2005). A multi-agent (MA) is like a GPS in a car. MA tells x where to go regardless of semantic reasoning. Much like a seeing dog for the blind leads a visually impaired person though a built environment. Also the word *rock* will exist once to be used for multiple purposes of meaning, e.g. to rock the chair, rock and roll, etc. Many forms of x may exist. The x is information in a K' or K domain. We now denote X to be all x's of X size. MA applies to all of X. The contra positive is not true. All of X does not apply to all MA's. MA's are independent unless bounded by some x in X controlled by the domain. Therefore, all X does not equal all X in regards to size of the information being exchanged. All x’s of X size are sub domains in some nD domain. We may have X1, X2...Xn. Not all X’s are in every nD domain. All K' and K have some group of x information we denote as Xn, but each group X of Xn can be different, and there must exist a synonymous X in K if K' has that same X. The sum of all X's must be a subset domain of the nDo.

The potential for all new nD's to utilize nDo exist. Assuming this condition is true, the potential for all K' and K to exist in every nD is true, and no nD will not have an X with sub domains of x in regards to information and the size of the information. The nD BIM prototype utilizes IFC as a constraint on X to contain x1 to xn information such as LEED, COBie, cost, etc. IFC also contains a property y named interoperability. So, information during interoperability, xy, is part of x information and contained in X information size. y interoperability is a constant and can be ignored as long as we do not change the schema of y, which is IFC the control in the IDFE model explained in chapter four. X information size is what will continue to grow exponentially due to the fact the world is collecting IFC BIMs as legal contractual submittals leading us to an object oriented model of the world. The “I” in BIM is for information and is the most important portion of the BIM process (Jernigan 2007). X size is the information dataset bundled as it grows over time.

We cannot fully constrain X because the information of newly created dimension will continue to exponentially grow over time. If we want to parametrically object-orient the world or universe as a parametric product data model with infinite benefit, then X has no finite size. If X has no finite size, then nD BIMs must have the necessary computational power to accommodate a global and universe BIM. Assuming the global and universe BIM will take exponential vector edges and vertices to visualize, at bare minimum in a virtual environment, it is wise to utilize high-level language parallel computing methodologies. MA's and SFR in the future will reduce dataset size and increase speedup. An object-oriented parametric product data model of the world and universe are feasible. We must share the x and X information through global agencies via IFC utilizing relational database technology in a distributed manner, and must utilize interoperable synchronization among dimensions. Hence, this is the need for nD Ontology. More computational power will constantly be needed as dimensions grow in the future to satisfy the needs of the AEC/FM industries. Ontological rules must be designated and designed to insure the nD BIM computational power developed in the future is created in a wise manner.

The philosophical ideas, frameworks, and ontology in this research are a sixth dimensional framework for the AEC/FM and the conception of an nD framework and ontology are necessary. Energy informatics was chosen for the sixth dimension because energy affects the whole building life cycle of any built environment. Before designing, during design and construction, and when the building is already complete, energy is the main concern that effects all dimensional processes. The EPAct of 2005 shows the U.S. government over the last decade has invested much time and money into sustainability and the analyzing of energy data for many sustainability reasons that will help mankind prosper now and in the future. The focus on a sixth dimension that is energy for the AEC/FM, arose because USA buildings are responsible for 30% of carbon emissions into the atmosphere and 60% of electricity usage around the world annually (Krygiel, Nies and McDowell 2008). When we utilize 6D energy BIMs, we choose to help mankind prepare for a better future by utilizing an integrated technological approach for more sustainable built environments that are in turn healthier for mankind. If currently the AEC/FM is making a huge paradigm shift to BIM integrated practice, then the feasibility of using the sixth dimension and any new n dimension increases dramatically. The AEC/FM is benefiting from those who have adopted the new technology needed to make the paradigm shift. Innovators and early adopter of technologies, such as BIM, are the pioneers of the new drastic change the AEC/FM industries. Jernigan (2007) reinforces that the U.S. government is benefiting from a $15.8 billion dollars savings annually for the year 2007 when utilizing BIM in the AEC/FM. Research also shows projects save 5-12% when utilizing BIM. There is a high demand for better analyses when using BIM and multi-dimensions within an integrated workflow process. To increase the amount of benefit and savings for the world, the AEC/FM must utilize multi-dimensional BIMs that exchange data in the most efficient manner. The exchange and sharing of data, interoperability, is the key to how the integrated approach works, especially when implementing the sixth dimension and future nD dimensions. To achieve the most gain from 6D energy BIMs the AEC/FM needs an ontological rule based system within their BIM workflow. For example, one holistic parametric data model and one file type, e.g. IFC schema, should be utilized to avoid redundancy and the waste of time, and expenditure during project development.

The exchange of information among dimensions in a BIM workflow must be seamless, which will allow the round tripping of data. One model for all dimensions allows just that, and with one file type the data to be exchanged can be interoperable in a bidirectional manner, therefore round tripped back into any dimension for reuse. If the file format changes for the one model BIM approach, then the workflow becomes unidirectional, which will not allow the round tripping of the data. Round tripping of the data is key to BIM and the seamless data exchange approach. Round tripping data allows information from any dimension to interact with all dimensions via relational database technology in a distributed fashion. The AEC/FM has the opportunity to achieved the one model and file format for the multi-dimensional approach. Then they will begin to see how the exchange of data through all dimensions can be used to make production easier, lower their current computational power needs, reduce waste, and increase monetary value. One model that has one file type for multiple uses can be stored in a web-based central repository in an efficiently accessible manner via upload, download, and query. This allows all AEC/FM actors to actively participate in the BIM process in real-time via the web throughout the whole building life cycle of projects. Web-based BIM, in a real-time virtual environment, utilizing a central database repository goes against the traditional AEC/FM approach, yet this new approach is the most efficient, beneficial, and least costly.

CHAPTER II

BACKGROUND

Currently, the AEC/FM industries are not advancing as fast as they would like. Utilizing open industry standards such as Industry Foundation Classes (IFC) is quite the hurdle for the conservative norm to adopt to keep up with the small majority of the world that are truly benefiting from BIM and interoperability. The change to adopting these technologies has proven beneficial in industry application worldwide, although adopting new technologies is difficult in the Architecture, Engineering, Construction, and Facility Management (AEC/FM) due to the hundreds of years of traditional practice. In fact the traditional AEC/FM practice predates the construction of the first pyramid developed in Egypt. Gourville (2006) explains the answer to why investors are unwilling to adopt new technologies. He stated that investors are unwilling to adopt new technologies because the investor must understand the change that is occurring, and they want to benefit before understanding exactly what needs to occur to change. Also, the investor's expectations are too high. They expect to benefit ten times than their normal practice when adopting a technological change in practice (Gourville 2006). Years of research show the conservative norm, e.g. firm presidents do not want to adopt many new technologies. There exist a large learning curve in the adoption of BIM. Moore (1991) in his book "Crossing the Chasm," shows a famous bell-curve illustration that depicts innovators and early adopter having no problem with the adoption of new technologies being they are at the forefront of the bell-curve and represent a small portion of the overall bell-curve area, but when it comes to the conservative norm and laggards, we have a long way to go implementing technologies such as BIM in the United States and on a global scale. The conservative norm and laggards represent the majority of the area within the bell-curve image. Many are unclear of what a BIM process is. Many refer to it as software. BIM is not software, but it utilizes software as tools to conduct a process. The lack of understanding the process knowledge of BIM is a misfortune for those who are trying to utilize BIM software tools in their current firm practices. BIM is a process. No one BIM is exactly the same as another (Jernigan 2007). The process of BIM is a personal one, with the intent to collaborate and share information utilizing interoperable schemas among actors in firms throughout the whole building lifecycle and the built environment in which the construction project resides (Eastman 2011; Jernigan 2007). The BIM message, according to Jernigan (2007 pg. 55), is to utilize the technology and resources at hand to "do more with less", and to create new technologies, as they become needed. It is unclear to many how they can create their own BIM processes and software tools. Hammer (2000) has spoken in high regards that technology changes at a fast pace, and therefore, companies should not reengineer their old practice and create tools to automate their traditional approach of business practices. The success in the future of BIM for the AEC/FM is dependent upon whether or not AEC/FM firms become innovators and early adopters rather than most being stuck in the conservative norm as they are now.

It is not surprising that integrated systems currently play a huge beneficial role in almost all industries on a global scale. In recent years the need to integrate in these industries has influenced the built environment designed by AEC/FM industries. Integrated systems have a changing effect on contractual agreements between actors in the AEC/FM. Traditional contracts are mostly 2D construction documents, but the country of Singapore and a few USA states are now shifting to accepting 3D IFC BIMs as legal documentation when submitting to government authorities, for example. This means if the stakeholders go to court then they will utilize a BIM during dispute and not the traditional 2D documentation that leaves much room for leverage among lawyers and little room for the architects, contractors, and engineers to support their case. The integration change for the AEC/FM is a huge paradigm shift that encompasses changing almost every aspect of the traditional approach and practice. The current name for this paradigm shift is BIM. Laiserin (2003) coined the term BIM in a debate started by him in 2003 but it has had many names over the past four decades, e.g. integrated construction methods and virtual building construction (Jernigan 2007), and virtual design construction (Graphisoft 2010). No matter what we decide to call integrated practice, the function will always contain methods and controls of input and output data and, utilize databases to integrate different aspects of the AEC/FM. A BIM is an object-oriented parametric data rich product model. This means we can add information into the 3D geometry and harvest it for various beneficial uses. Also, when a change is made in one dimension, it automates the change into the other dimensions; e.g. take a window out the model and see the window disappear on the construction documents and in the schedule, and the overall budget cost will change as well. Then, this information can be integrated into systems for analysis and simulation utilizing a database, and the information can also be recycled or reused on future projects.

This approach is far from the traditional pen and paper approach that has existed for thousands of years. Tufte (1990) explains the worlds industries are getting away from the 2D flatland approach. Traditionally, 2D construction documents, *blue-prints*, were the norm. The change to 3D models allow better communication and collaboration among stakeholders in the AEC/FM. Currently there exists a huge learning curve in understanding 2D documentation because it forces the human brain to have to visualize in their mind the isometric 3D visualization from the 2D construction documents that are the norm in traditional AEC/FM practices. When a layman citizen goes to a city council meeting, where the citizens have the right to voice their opinion on new town developments, the citizen does not speak because she does not understand 2D construction documents. The reason 2D documents are being used is because it is the law and current legal document submittal. The change happening now is some US states are requiring BIM models to reduce the learning curve caused by 2D. Some countries, as stated earlier, such as Singapore has made it mandatory that only IFC BIM models are to be presented for built environment decision-making and legal processes (O'Keeffe, Shiratuddin, and Fletcher 2008).

The AEC/FM paradigm shift, BIM, actually comes from the automotive industries in Europe dating back to the 1960's (Jernigan 2007). These philosophical ideas are now being applied to the AEC/FM industries to reap similar benefit such as increased value and reduction of waste. The good news is that BIM is a process growing at a very fast rate, and its benefits can be seen on the very first project if applied properly (Jernigan 2007). These benefits include reduction in waste, time, and cost savings (Bazjanac and Crawley 1999). BIM is a process, that when applied correctly can bring great reward, e.g. no more redundancy that wastes much time and monetary expenditure (Eastman et al. 2011; Jernigan 2007). Because these redundancies exist, many AEC/FM actors are having to model 3D conceptualizations from 2D document to communicate efficiently, construct the building, estimate, and in general find problems virtually before they occur in real-life, which in turn saves lives and money. In 2D it is very difficult to visualize to the extent of solving problem before they happen and this actually causes many deaths per year. Basically, because the intention of 2D documents is to communicate the design for construction, not to save money or human life. It is normal in traditional practice to find many costly problems on the construction site due to unclear 2D construction documents; therefore, many times these actors end up in a legal dispute. The first approach when using BIM is to model a 3D object-oriented model. Next, add parameters to the object-oriented model that will be utilized to conduct analysis and simulation. The parameters are also the primary link between model and relational database via the relationships they have embedded as tags in the code. This is where the tags exist for the relationship between objects needed to extract information from the database. Finally at this stage a BIM is actually producing reward and benefit, saving human life. The integrity of the BIM is its information. Jernigan (2007) stated that the *I* in BIM is the most important aspect to consider. If we do not put in quality information, e.g. use appropriate standards and schemas, then the information is worth nothing.

The type of primary information needed for use embedded into a BIM is, quantity of object-oriented element geometry, scheduling of task, cost, standard building codes and resources, manufacturer, energy information for sustainable built environments, and any relatively beneficial information for a projects duration of the whole building life cycle. The importance of the information has been to derive new dimensions for the AEC/FM. Included are 2D (construction documents), 3D (BIM), 4D (scheduling), and 5D (cost). It is clear that the 2D-5D dimensions are extremely important to a successful implementation of BIM, but what about the other information, such as energy information, that is certainly as important to the whole building life cycle especially since the federal governments employment of the EPAct of 2005 that states environmental needs must be of a concern especially to the building industries. To solve this problem, it is necessity for a sixth dimension named energy. 6D energy can benefit the whole building life cycle, which includes the whole duration of time the building exists in any given environment (O'Keeffe, Shiratuddin, and Fletcher 2009). A 6D energy dimension, which is an IFC compliant interoperable dimension, can improve building performance energy simulation. Energy simulation modeling is also explained briefly in Bazjanac (2003).

The way 2D-6D works is like a ring of messages being passed along for communication. Similar to a ring network topology, the data should be able to be round-tripped with no loss or corruption of data. Round tripped data should have no loss of information and structural integrity, from input to output back to input. The highest quality BIM of is achieved when round tripping data can be performed. This type of BIM is designed to be the most efficient in practice.

Literature Review

Governments around the globe are concerned about energy, water, carbon footprint, indoor and outdoor air quality, harvesting of regional material, and disposal of waste. Buildings affect the livelihood of all living species through their consumption of energy, resulting in pollution and ozone depletion. Buildings are also consuming 5 billion gallons of potable water per day (Krygiel, Nies, and McDowell 2008). In the USA alone, buildings consume approximately 37% of the world energy and 68% of the world electricity United States Green Building Council [USGBC] (2007). The USGBC developed the standard Leadership for Energy and Environmental Design (LEED), which is an energy standard utilized to certify green buildings globally, using the Capital E assessment which is a premier provider of strategic consulting, technology assessment and deployment, and advisory services to firms and investors in the clean energy industry. Capital E has reported average energy savings of 30%, average carbon reduction of 35%, a savings of 30-50% on potable water use, a reduction of land filled waste of 50-97%. In 2003, Capital E developed an average first cost premium of 2% based off 33 LEED certified buildings in California (Krygiel, Nies, and McDowell 2008).

Sustainable buildings are not something new, but only recently have governments made sustainable development mandatory. In 1987, the World Commission on Environment and Development said to the United Nations that sustainable development must meet the needs of the present without compromising the ability of future generations to meet their own needs. A good analogy and example of sustainable design is the Native American teepee (Krygiel, Nies, and McDowell 2008). The teepee is designed using regional materials and it does not compromise the future of the land, deplete the natural material sources, or compromise the people who will inhabit that land. Teepee materials are recycled back into the native environment without waste and damage to infrastructures. Currently, a typical USA construction project generates 2.5 pounds (~1.13 kilograms) of solid waste per square foot of floor area. Forty percent of total waste in the USA is caused by construction and demolition, and LEED is helping some project to achieve an 80% waste diversion rate (USGBC 2007).

The statistics bring forth a need to provide an energy dimension, which is an efficient way to utilize sustainability information using BIM. The vision is that the 6D energy BIMs that include LEED energy standards will reduce the duration of LEED certification process, provide certification information that can be achieved in a timely manner, and be able to select different types of material and how they effect cost. By doing so, the AEC/FM industries in general and project stakeholders in particular, can benefit from better tracking and forecasting of sustainability information, and construction events early on in a projects life cycle. By reviewing specific LEED credits within a 6D BIM virtual environment, a standard review process working in parallel with the BIM model can be achieved, unlike the traditional 2D paper-based LEED review method for certification.

Currently researchers are arbitrarily using the term 6D, 7D, 8D…nD for BIM. 6D or 8D are used to make a general reference to nD BIM, a new dimension *nD*, like Facility Management, Sustainability, Safety, Crime, etc. in the utilization of their BIM, but neither published papers nor journal articles have defined any dimension beyond the 5th cost dimension for the AEC/FM industries that have a framework or set of rules. There is an 8D BIM paper by Kamardeen (2010) that has a respected 8D BIM model for accident prevention, which is a prospect for some new nth dimension, but the paper does not describe a framework of how or why 8D was chosen as the dimension. When thinking of a defined 6D, it brings about the idea that any nD additions to the BIM should be specifically defined and includes the use of pre-existing standard international and national schema, e.g. Industry Foundation Classes (IFC), to comply with the current existing BIM workflow possibilities. The intent of 6D is to stretch beyond any current nD addition to the BIM by specifically defining additions to currently existing BIMs. 6D allows the designers and all stakeholders to have energy informatics available during the entire building life cycle via querying a relational database repository, from schematic design to construction, and beyond with the ability to utilize an As-Built BIM for Facility Management while still containing the energy informatics for future reuse. Prior, in traditional methods, As-Built models were modeled after, not before, the construction took place. The proper way to utilize the BIM process is to create one model that can be utilized throughout the whole building life cycle (O'Keeffe, Shiratuddin, and Fletcher 2009).

Lee et al. (2005) at the University of Salford, UK are working on the nD concept. nD is a respected concept of multi-dimensional BIMs that can support advanced design and construction methods. The AEC/FM community struggles with creating a function to add new specific dimensions and how the new dimensions will have an effect on other dimensions in the BIM workflow throughout the whole building life cycle. Aouad, Lee, and Wu (2007) in their book on nD modeling mention a vision of nD modeling being the future of the AEC/FM, but they did not have a clear way to explain nor implement nD in the current practice of today’s industry. Aouad, Lee, and Wu (2007) theories prophesize that new methodologies for the AEC/FM will come through research around the world all working together in harmony. This is the reason why an nD framework is necessary and nD ontology must be created. A unified framework and ontological rule based system will allow the AEC/FM to collaborate and communicate nD dimensions in a clear way.

Martin Fischer, through a series of many papers and case studies, has coined the term 4D for the AEC/FM industries. 4D can be referred to as visual representations created in 3D that also includes the element of time passing and can be found from Mc Kinney and Fischer (1997). For the AEC/FM, 4D refers to 3D BIM software tool that is interoperable with a project schedule duration. Mc Kinney and Fischer (1997) found that 4D (3D + time) is a way for the AEC/FM to solve problems early during design phases versus have to solve problems during construction, by use of a 3D virtual representation of the project interoperable with the schedule via file format and schema. 4D is a way to solve problems like delays, re-design and damage to an existing structure. Dawood et al. (2002) explain the 4D concept also allows better construction sequencing by use of virtual environments, and a 4D BIM allows the comparison of many schedules to see which one is best suited for a specific project and virtually watch animations of the model develop and play key frames over time for clearer communication and collaboration among stakeholders.

5D can be referred to as visual representations of cost information created in 3D that also includes the element of time and budget expenditure. VICO (2008) introduced the world to 5D, and 5D BIMs are currently being used globally on projects to reduce waste and save time and revenue. A 5D BIM is a time and construction simulation model that is a virtual building model containing cost and project management informatics in a reusable database repository (Laine and Karola 2007). BIM virtual environment that 5D is the interoperability of a single design and construction model (3D), schedule (4D), and cost database (5D)(O'Keeffe, Shiratuddin, and Fletcher 2009). When utilizing 5D methods the user can change any dimension and the other dimensions automatically update through a synchronized relational database to reflect the change in all dimensions (VICO 2008). 4D and 5D allow the AEC/FM professionals and especially the owner to utilize simulations to ensure a project plan is feasible, efficient and within the budget parameters. Benefits of 5D include better communication and collaboration among stakeholders, analysis of site logistics, trade coordination on site, and comparisons of schedule and tracking of construction progress (Eastman et al. 2011).

The nD concept is a great theory to get minds thinking and innovating, but when it comes to integrating new dimensions into the BIM workflow, we must be specific in order to communicate the new dimension efficiently according to standards and codes. There are nD tools being developed in Europe, but the dimensions have a disjointed interoperable framework that does not round trip data through all dimensions, and there is no ontology for others to create nD tools with defined dimensions that are agreeable worldwide. We as an industry must ask what are the rules to go by and where are the rules and roadmap to be successful in our endeavors to establish such integrated new dimensions in BIM processes and tool systems. This dissertation discusses many aspects of the multi-faceted, multi-dimensional AEC/FM world we all live in and how an object oriented nD framework and ontology is essential to the innovation of IFC BIM processes on a global scale.

Currently energy performance information is not being stored in database repositories for future reuse. According to Gu et al. (2008) all data throughout the project life cycle should exist in a single project data repository. The VICO 2008 software proprietor states 4D scheduling and 5D cost models that are interoperable via a single repository database were created due to an owner client request for the architectural design and construction information models should be one single model. Laine and Karola (2007) agree that the AEC/FM can benefit from data repositories throughout the whole building life cycle and be capable of more efficient data input and reuse of energy analysis model information. Energy analysis BIM information should be available via a databases repository to be developed, currently ongoing and future projects. The information in the BIMs can be used on projects, and the information that comes from and on future projects that may need to be able to reuse already stored energy information in the database repository. When 6D begins to be implemented, the AEC/FM have only scratched the surface of the feasibility of the new ideas 6D brings to stakeholders.

CHAPTER III

METHODOLOGY

Utilizing Object-Oriented Parametric Modeling and Virtual Construction Methods to Develop the 6D BIM that Contains Standard Energy Information.

Utilizing 6D energy BIMs to maintain and select regional materials improves the development of buildings that are sustainable, and this is a huge change for the AEC/FM industry to benefit further from a BIM. A 6D BIM is a construction–time-simulation model of a virtual building that contains schedule, cost, and standard energy related information. The 6D BIM is defined as the linking of the 3D design and construction model, 4D animated schedule duration, 5D cost information, and 6D energy information utilizing an international energy standard. 6D is (3D[height + length + width] + 4D[schedule] + 5D[cost] + 6D[energy]), and shows how 6D BIMs are also an example of how the nD concept may be applied to the BIM workflow for energy O'Keeffe, Shiratuddin, and Fletcher (2009). 6D should be known as energy, due to the fact energy is an important and integral component of current AEC/FM design, construction, and facility management processes. The Department of Energy (DOE) speaks of the high demand for energy to be a critical part of the AEC/FM in such articles published at Harvard University by Gallagher et al. (2006). Energy has an effect on the whole building life cycle. If 6D is not energy, stakeholders will continue to overlook integrated energy informatics in their design, construction, and FM practices, or not be able to comply with federal and state demands of the EPAct of 2005 for sustainable built environments. 6D will allow a standard to abide by for energy compliance which will be more feasible for designers, builders, and facility managers during the whole life cycle of a building; for example when 6D is energy, the AEC/FM has energy as a standard that can be integrated into currently existing BIM workflows as proprietors begin to supply the technology to meet the demand for energy informatics early in the design process and throughout the whole life cycle of a BIM that is not supposed to die or become stagnant (Jernigan 2007). Energy data can then be round tripped though all dimensions.

Lee et al. (2005) writes that nD is communication visualizations beyond 3D and 4D. This may be confusing to the BIM user because they may have heard of 5D, which does exist and is not nD; it is specifically 5D (cost) for a reason. 5D is a collaborative communication method, but we specifically speak the terminology 5D BIM so all stakeholders know we are discussing cost. If we say nD to stakeholders, then they may ask what is nD. This becomes very confusing because the term nD is very vague. Energy informatics integrated in the BIM should be 6D so there is no confusion of the topic when being discussed, and future nDs should be defined specifically. Also, there is 5D software. The author has developed the nD BIM software application integrating 6D and other dimensions, but the dimensions are specifically defined and follow the author's framework and ontology described later in this doctoral dissertation.

When we are specifically defining 6D BIMs verses the current vague abstract nD concept, we must consider the efforts for interoperability of the BIM for energy analysis will continue to be a problem if the AEC/FM does not utilize a bidirectional workflow for energy informatics communication. The AEC/FM needs 6D to integrate standard energy information into a current BIM workflow. A similar concept is mentioned by Lee et al. (2005) in their endeavor to bring more nth dimensions into the BIM workflow by utilization of advanced technologies, but they also include that nD is ideal but not achievable for short term due to the unwillingness of stakeholders to work together. As stated earlier, the famous bell curve demonstrating the unwillingness of industry personnel to adopt technologies and effectively working together can be recognized in "Crossing the Chasm" by Moore (1991).

If nD was broken down into specific dimensions, then there would be less confusion among stakeholders and they may be more willing to work together because they will be on a common ground when communicating. Recent case studies on 5D provided by VICO (2008) demonstrate a willingness to work and collaborate utilizing specifically defined dimensions in 5D software, and they state that 5D has proven to be a great benefit among all stakeholders, especially the Owner, A/E, Contractor, and Sub-Contractors.

The 6D BIM Workflow

Shown in Figure 1 is the interoperability for BIM, 2D through 6D…nD, and implements the idea of nD for the future dimensions to be interoperable and the data to be round tripped. The whole BIM workflow presented in Figure 1 is designed for round-tripping IFC project data in a bidirectional interoperable manner. The theory is that all data should be able to be imported, exported, edited, re-imported, stored in a single data repository, reused in the future, and all data in each dimension effects all other dimensions, 2D…6D…nD O'Keeffe, Shiratuddin, and Fletcher (2009).

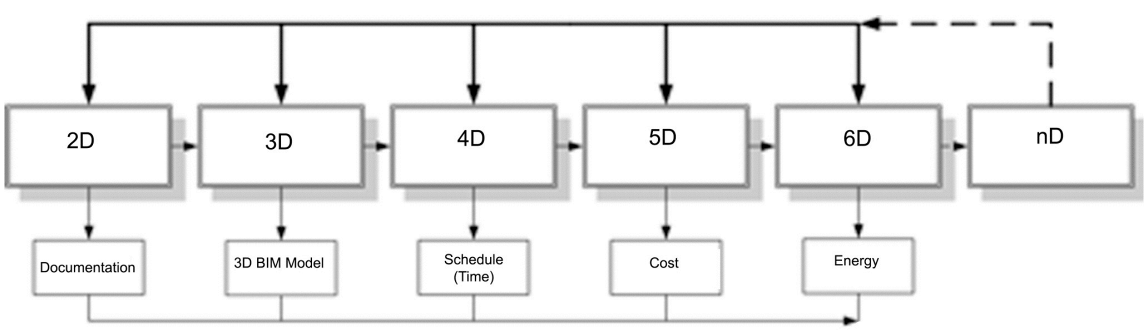


Figure 1. The 6D BIM Workflow. The Figure shows, from left to right, the interoperability between dimensions 2D - 6D and any nD for the future using the IFC Schema. It also shows all dimensions are linked to interoperate together, e.g. if a window

is deleted from the building model all other dimension reflect the change that was made in the 3D model containing the window.

IFC Limitations During Interoperability and Query of IFC Data

The ten current limitations of IFC 2x3 are the missing energy information needed for IFC energy performance analysis, and they are Building Type, Services, Location, Construction Assignments, Units, Lighting, Equipment, People Loads, Air Flow Data, Building Materials and curvilinear surfaces for GREEN design. The IFC 2x4 schema that is in its beta1 version stage should resolve these issues, but the testing by the industry and Model Support Group (MSG) of the International Alliance for Interoperability (IAI) is not complete.

Solving the problem of IFC limitations is a complex process, and it is possible to add to the schema architecture and resolve these issues. Amore, Jiang, and Chen (2007) found that many software proprietors have adopted the IFC schema, and modifying the schema is the future of the IFC. The buildingSMART IAI MSG will need to modify the currently existing IFC data model architecture. Refer to Figure 2 and begin at the top of the IFC data model by locating the Domain Layer. There is no energy domain layer, so one may need to be created for energy information to be supported by IFC compliant software. Next, modifications to the interoperability layer will need to take place so energy information is not overlooked during the interoperability of information across software platforms. A new Zone core layer may need to be created for energy as well. Currently, there exists a Zone layer in the Kernel, so maybe modifications to the preexisting Kernel layer are needed for interoperability of energy information. Lastly, the Resource layer that can allow energy cost calculations to be possible due to the fact that currently product and material cost is extracted from the IFC BIM data file.

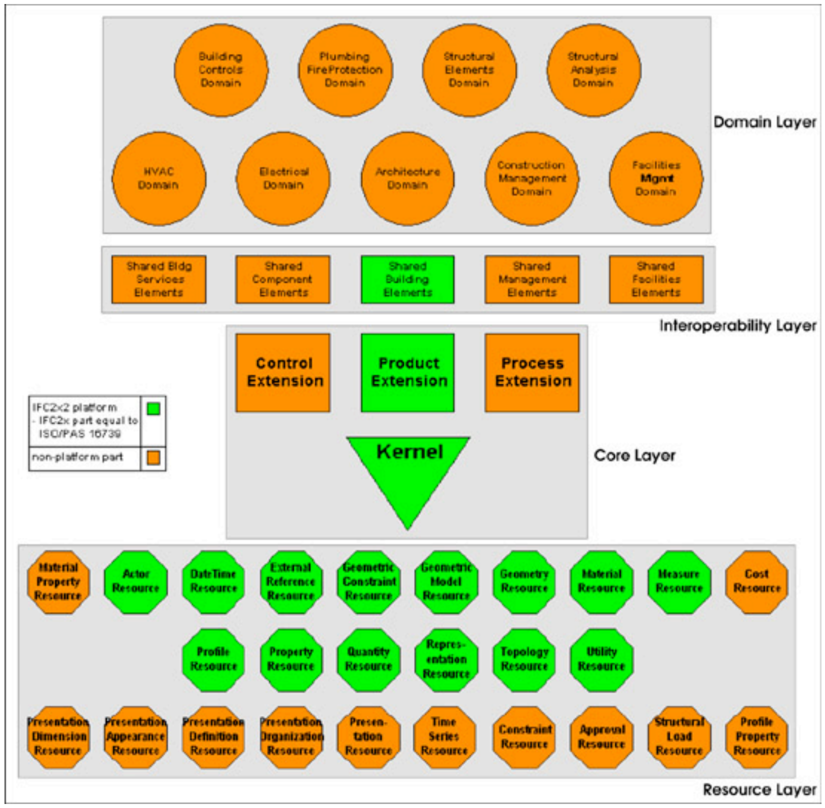


Figure 2. The IFC Schema Architecture. The Figure shows, from top to bottom, the Architecture of the IFC Schema. The schema begins at the top with the Domain layer. Next is the interoperability and core layer, and the bottom shows all available resources in the resource layer. The green portions of the IFC Schema and currently certified through the MSG of the IAI and the orange are in process. International Alliance for Interoperability (IAI 2011).

In the future a new domain for energy should be added to the currently existing architecture of the IFC data model schema. This is a feasible idea due to the rapidly expanding additions of the IFC data model. There is a new IFC Electrical Domain in the IFC 2x4 beta1 version, but it only encompasses the energy of lights and cables and not all energy of the built environment, and this information can be found from the (IAI 2011). The IFC architectural model has information added to the schema over time by the IAI MSG when the industries needs become applicable. New information added to the IFC schema goes through a long testing process by the MSG.

The AEC/FM needs energy information interoperable via IFC file format and schema. The vision for a 6D…nD BIM is that one single BIM, with one single IFC file type, is used for 2D – 6D…nD. The one model and file format hypothesis can be accomplished by utilizing the IFC file format and schema. At the current time, the IFC schema architecture is currently limited when utilizing it for energy informatics query, but it does contain the integrity of fulfilling the goals and objectives of energy query if a new energy domain is created. Interoperability among platforms can be achieved by using the IFC platform neutral file format and schema. IFC allows the capacity to store and share 2D – 6D information, especially energy simulation IFC data explained by Bazjanac (2008). In order to query energy information in a formal since an energy domain should be created in the IFC Architecture. Some energy analysis simulation software proprietors are in the process of becoming IFC compliant. An example is Autodesk Ecotect, which currently imports IFC models, but does not export IFC models. Bidirectional energy informatics sharing and round tripping data is accomplished when software applications allow export and import of IFC models. This allows for the reuse of energy information in the BIM software and energy informatics to be utilized by all nD dimensions, the dimensions that exist now and the dimensions to exist in the future. The storing of energy informatics includes a database that is linked to the 3D BIM software allowing the new 6D BIM information to connect to pre-existing 2D-5D BIM workflow information. The IFC file format can be used for interoperability and storage of energy information by use of object-oriented parametric modeling tools, and IFC is utilized for the file format for bidirectional energy performance model and information that can be stored in a single data repository.

When utilizing a 6D model, users can change any information in any dimension, and because of the synchronization database that links the dimensions in an interoperable fashion, all dimensions are updated to include any added, deleted or changed information (O'Keeffe, Shiratuddin, and Fletcher 2009). 4D, 5D, and 6D allow AEC/FM professionals and the project owner to utilize simulations for "what-if" scenarios to ensure a project plan is feasible, energy efficient, and constructed at the lowest cost possible. The benefits of using a BIM include the improvement in communication and collaboration among stakeholders, and better analysis of site logistics, trade coordination on site, and comparisons of schedule and tracking of construction progress (Eastman et al. 2011).

The 6D BIM Prototype

The 6D BIM model with embedded energy information was developed using a suite of software by VICO, who was recently bought by Trimble. Sustainability information for LEED certification purposes, which is considered the sixth dimension energy, is embedded into the model element parameters via an estimating database repository connection with the BIM. Besides being utilized for LEED certification, the energy information can be used for GREEN building record such as construction material cost, labor cost, energy cost, the duration of which GREEN energy efficient materials are installed, Construction Specifications Institute (CSI) UniFormat design classification, Master Format methods of material installation, task progress of material installation, and when the materials are completely installed with a summed cost for all. The 6D BIM model can also be used for Earned Value Analysis (EVA). The EVA allows the user to simulate the "what-if" scenarios and see how cost is affected over time throughout the whole building life cycle and provides the infrastructure to meet the owners budget target cost. Inside the 6D BIM EVA viewer, the 5D cost related information includes labor, material, sub-contractor information, equipment, energy standards, etc. Reports of all EVA query can be exported to a Microsoft Excel spreadsheet that allows for further interoperability and data exchanging with other BIM software tools. Users can navigate in real-time through the 6D BIM virtual environment and access the LEED sustainability material information and the attached energy cost for those materials.

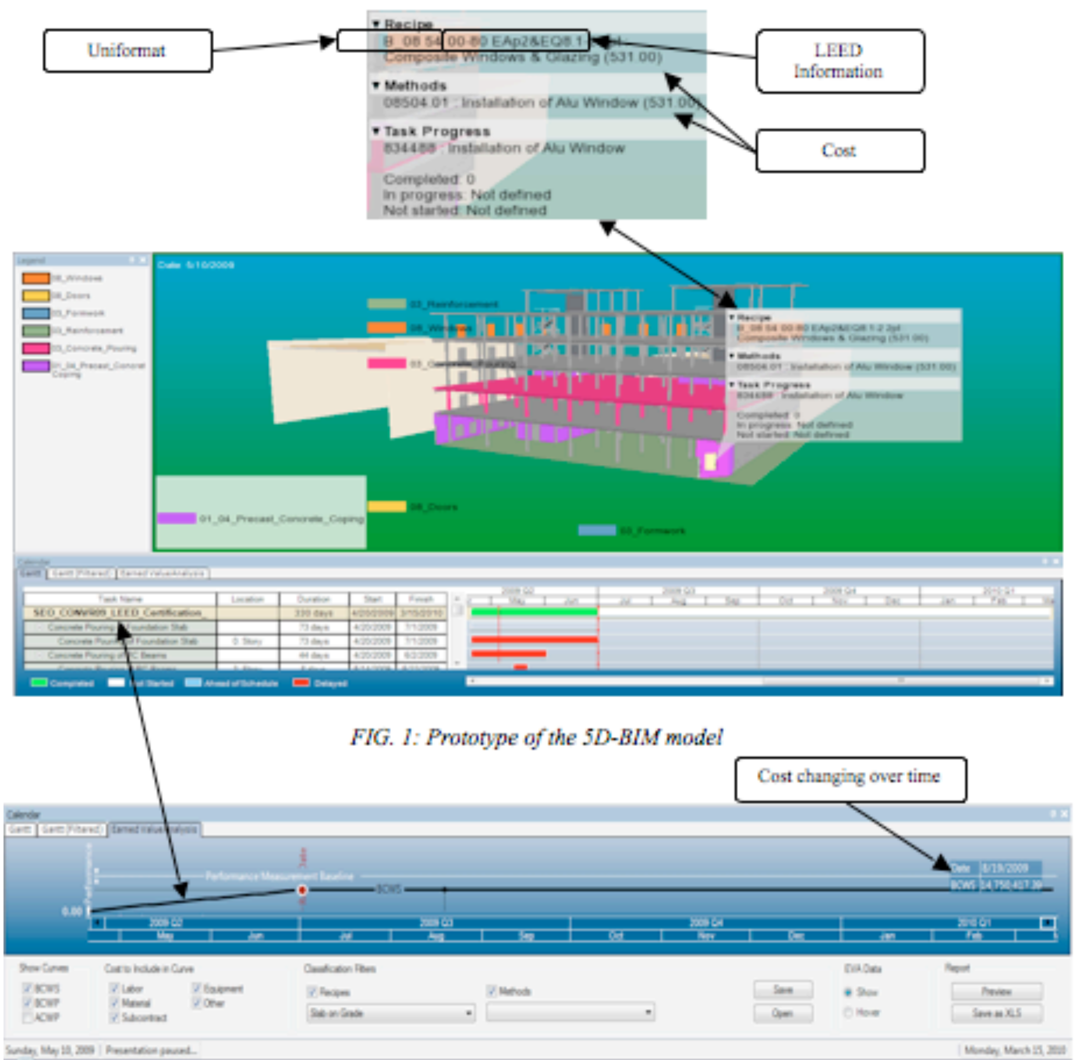


Figure 3. A 6D BIM Prototype. Shown here is an Embedded Schedule, Codes, Cost, and Energy Information.

A LEED Project can be certified as one of four different levels of certification depending on how many points are achieved from the GBCI. The four levels of certification are Certified; 26-32 points, Silver; 33-38 points, Gold; 39-51 points, and Platinum; 52-69 points (Krygiel, Nies, and McDowell 2008). The type of LEED Project certification depends on what category the project falls under: LEED for New Construction (NC) and Major Renovation, LEED for Neighborhood Development (ND), LEED for Schools, LEED for Existing Buildings, LEED Core and Shell, and LEED for Existing Buildings Operation and Maintenance. The prototype for this paper utilizes the LEED – NC Version 2.2. There are over 900 certified buildings and almost 7,000 more registered seeking certification as of June 2007 (USGBC 2007).

Figure 6 shows a workflow diagram for a successful inclusion and use of LEED information in a 6D BIM model. The LEED information can be viewed and reviewed in real-time within a virtual environment. To include the LEED information into the BIM, a new custom recipe must be created for the model elements. The recipe is then saved in the project estimating relational database and will now contain the LEED information, labor methods, cost, and sustainable resources. The project-estimating database allows the model element's recipe to be interoperable among the multiple BIM workflow dimensions. The VICO software was used to produce an interoperable information workflow for a LEED ready 6D BIM model. Figure 5 shows the relationship between cost and LEED credits viewable via the BIM software. The LEED ready 6D BIM model can then be viewed and reviewed within a virtual environment using the VICO 5D Presenter software. In the 5D Presenter, users can access and visualize the cost, LEED information for certification, 4D schedule, and Earned Value Analysis. Users can also watch the 6D BIM model develop over time as a collaboration simulation model in the

VICO 5D Presenter.

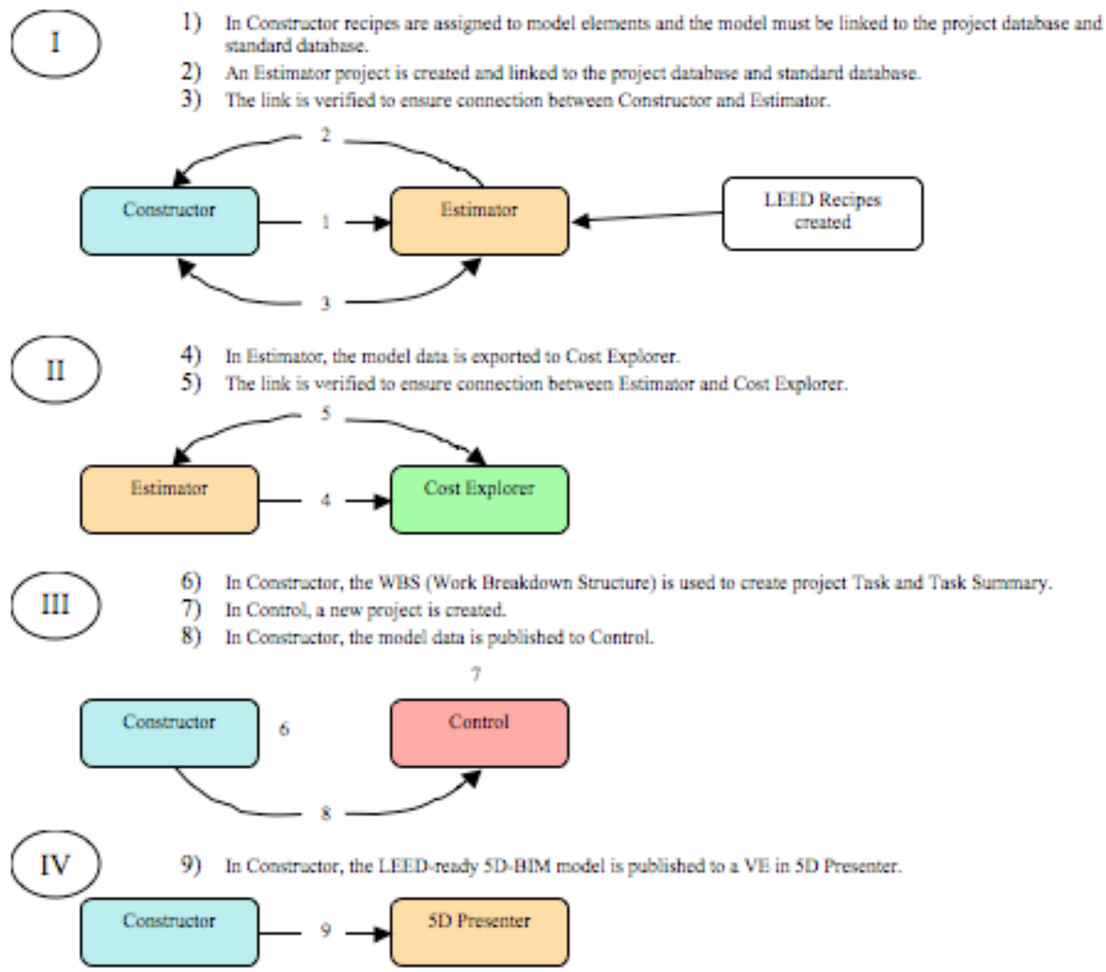


Figure 4. Workflow for an IFC 6D BIM with Embedded Energy Information.

The information necessary for the review of LEED certification is provided by the USGBC. The LEED information in the model element parameters contains a LEED credit number that can be referenced to a digital or paper-based LEED summary checklist. The checklist contains the credit title, intent of credit, requirements, strategy, and submittal documents. Each credit number has a specific number of points. Using the LEED ready 6D BIM model for certification, users are allowed to access the LEED credits and points in real-time in the virtual environment. The LEED certification process can be done in a virtual environment if the credit numbers and requirements are embedded into the BIM model during the Design Development Phase of the Project Life Cycle.

LEED standards within a virtual environment allow the AEC/FM industry to move forward to a more integrated and automated approach. LEED certification in a virtual environment will help the AEC/FM manage sustainability information when utilizing a BIM model, and the BIM model can supplement the certification process. LEED certification in a 6D BIM model provides various benefits including the reduction of cost of sustainable design, providing various *what-if* scenarios to achieve better sustainable designs, improving real-time communication of certification intents, and reduction of the time wastage that occurs when waiting for submittals to be approved for certification. Overall, this could lead to healthier and more efficient built environments.

Verifying Energy Performance Data

Finding ways to verify energy performance is not an easy task. Utilizing BIM is a practical way to verify energy performance. Without using BIM it is hard to verify the energy performance of the whole building life cycle. Energy Performance information should be stored in a single database repository for the reuse of data on future projects. The IFC schema can be used for interoperability and storage of energy information by use of object-oriented parametric product data modeling once the limitations of the IFC architectural model, for energy analysis purposes, is reviewed and solved by the IAI MSG. The use of IFC for the file format for round-tripping bidirectional energy performance model data and information that can be stored in a single data repository is shown in above Figure 1. Energy analysis includes the DOE (Department of Energy) Weather Database that provides the annual weather data. Weather data is integrated into the BIM for calculations and simulation. The AEC/FM can benefit by using energy performance analysis software to produce the energy analysis calculations and simulations. Utilizing calculation and simulation data for LEED Green Building certification submittals also include benefits for urban city planning.

The types of weather data files are WEA files and the DOE .EPW files, and are different depending on proprietor but they function the same when geolocating and performing energy analyses of the built environment when utilizing BIM software. The data is supplied from the US Department of Energy (DOE) globally as can be noticed in Figure 3. This energy informatics data are the types of data to be used for building and built-environment performance analyses. The data in Figure 3 includes average, maximum, and minimum temperature, relative humidity, direct solar radiation, diffused solar radiation, average wind speed, average cloud cover, and average daily rainfall.

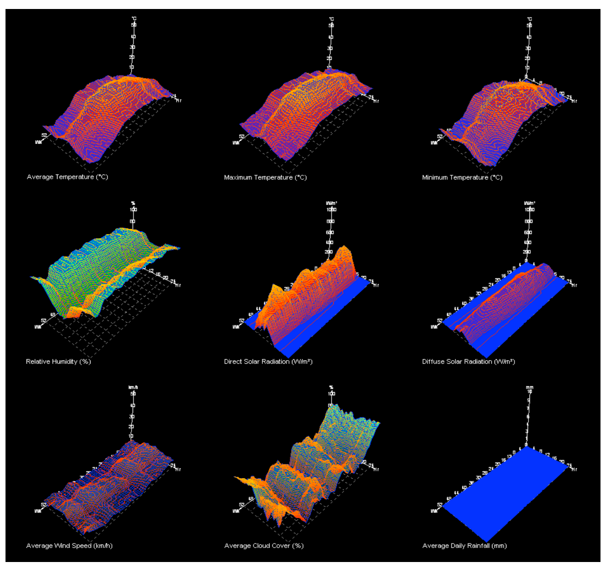
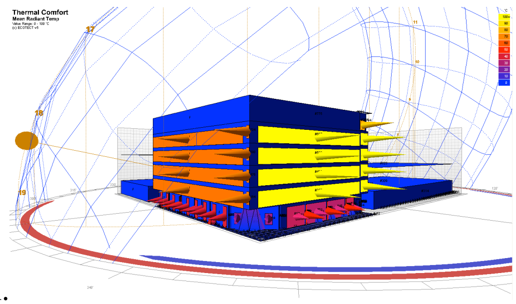
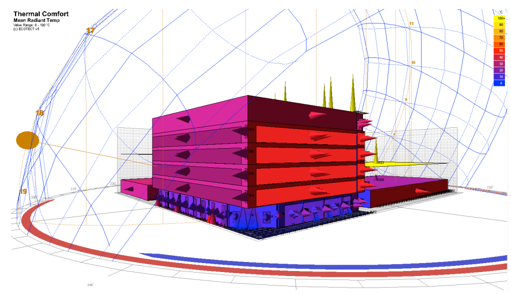


Figure 5. Department of Energy (DOE) Weather Data. The DOE database supplies data for any given land area in the world. The image shown is the weather data for Hattiesburg, MS, USA. The image shows utilizing the Ecotect weather database.

The types of 6D IFC BIM energy analysis include shadow ranges, solar rays, solar projections, views from sun pos, sun-path diagrams, solar access analyses, solar exposure, lighting analyses, right-to-light analyses, advanced day lighting, photo electrics and daylight factors of daylight autonomies, thermal analyses, indoor and outdoor comfort analyses, building regulation codes, spatial visibility analyses, prevailing wind data analyses, resource consumptions, materials and curvilinear surfaces. All of these energy analyses are necessary for LEED energy certification of buildings and built environments. Some of these visualizations of data analyses can be found in Figure 4.



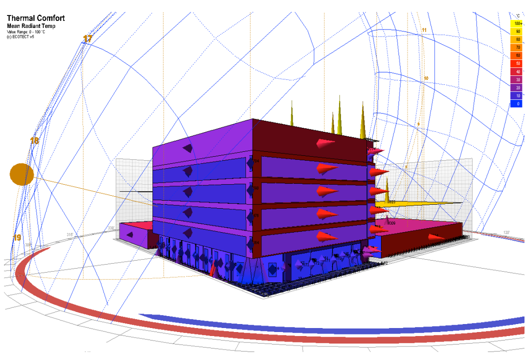
A.



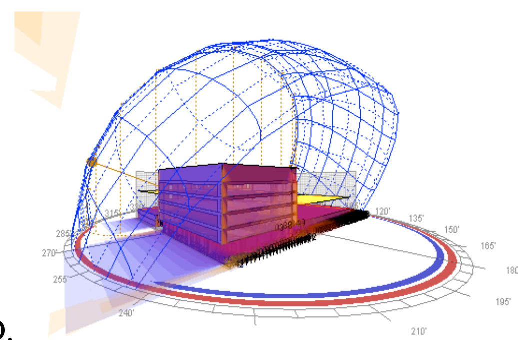
B.

Total Transmitted Radiation

Total Incident Radiation



C.



D.

Total Absorbed Radiation

Thermal and Shadow Simulation

Figure 6. IFC 6D BIM Energy Simulations. These simulations are created from an IFC BIM. A, B, C and D are simulation types created in the Ecotect software. Image D is a rendering of an animated simulation of photovoltaic energy values over the course of one full year.

The Creation of Custom GDL Objects with Embedded 6D BIM Energy Informatics

The Geometric Description Language (GDL) is a computer-programming language that allows for the creation of GDL based object libraries used in BIMs. GDL objects are object-oriented parametric based object elements, and they contain all the information required to describe architectural building elements such as 3D geometric model, 2D CAD symbols and texts (Graphisoft 2009). GDL models can be modeled or coded depending on the preference of the model element developer. In order for GDL models to be 100% IFC compliant they should be coded in the appropriate manner, e.g. embedded with the correct IFC schema for interoperability, or the model can be exported from a GDL BIM software, e.g. Graphisoft ArchiCad, which will allow the GDL model to be compliant with other IFC supporting software. ArchiCad is the only GDL supporting development tool for BIM. A list of all IFC compliant software can be found the (IAI 2011). The information in GDL objects is organized in a structural tree hierarchy, based on the IFC schema (Graphisoft 2009), although as previously stated the research shows not all GDL object models will interoperate with all IFC compliant software unless the appropriate schema information is embedded within the code of the GDL model parameters, e.g. the IFC 2X3 schema that all proprietors are currently utilizing. In the near future the IFC schema to be utilized by proprietors is going to be the IFC 2X4 schema once it has finished being tested by the industrie's early adopters and going through the thorough stages of development by the MSG. One industry leader that has tested the IFC 2X4 schema is Dr. Bill East of the USACE in the Champaign, Illinois district. He is an early adopter of the IFC 2X4 schema and has conducted years of testing the IFC 2X4 schema for the IAI MSG. Currently the IFC 2X4 schema is in beat1 stage. Using GDL objects allow the creation of many additional building information parameters that can be embedded into model elements present in the AEC/FM. Such information desirable to be embedded are the creation of LEED related model element parameters in conjunction with the IFC schema, and can be produced by creating the necessary parameters utilizing the GDL script editor in ArchiCad. A developed prototype nD BIM that contains GDL objects embedded with LEED related information and actual energy model cost of architectural design and construction products. Also in the following chapter the methodology for the various parameters that are embedded in the nD BIM prototype software the Virtual LEED Review System created for the USACE ERDC, and allows the user to utilize one IFC BIM, that can be interoperable with BimServer and Virtual Environments that can produce cost and energy calculations from the parametric data within the object-oriented parametric BIM (Fletcher et al. 2011).

The importance of a BIM model element is it allows for the input of critical information needed during the whole facility life cycle. Information is what BIM is about (Jernigan 2007). Information is embedded into a model element by entering information into the model as object element parameters. A BIM software tool that is fully interoperable, IFC compliant, must support the IFC 2X3 file format and schema. IFC allows the interpretation of model element data via the IAI currently now known as BuildingSMART. IFC BIM LEED parameters added to the GDL model elements is the extreme focus for energy analysis to support the LEED certification of the built environment, but at this time there is no direct LEED schema in the IFC architecture to support the interoperability of the LEED model element information. In other words, the nD BIM prototype forces the LEED IFC compliance of BIMs with the methodology described. The nD BIM prototype was developed to share the IFC BIM LEED information for BIMs via the developed custom nD BIM software application by utilization of virtual environments, created using game engines, and the use of the custom advanced relational database linked to the BIM.

Also, cost for the LEED IFC compliant objects was embedded into the model element parameters of the GDL objects for 4D and 5D BIM simulations. The virtual cost embedded into the parameters represents the actual cost of the product to be erected on the construction project site. In the prototype created by (O'Keeffe, Shiratuddin, and Fletcher 2009) demonstrates that the creation of LEED information plus cost embedded into the GDL model element parameters reflects a LEED cost relationship using the sixth dimension known as 6D. In the future, more GDL object custom parameters created by users will be IFC interoperable when more subset schemas and a domain layer is developed by the IAI MSG, and it is possible other methodologies may also be developed by future researchers. The author is currently researching and experimenting with the creation of new subset schemas and an energy domain layer for the IFC to be proposed to the IAI MSG. Sustainable built environment information should be interoperable via the IFC schema to provide efficiency and future cost benefits for the AEC/FM.

Leadership in Energy and Environmental Design (LEED)

Internationally, the AEC/FM and academic researchers are concerned about energy, water, carbon footprint, indoor and outdoor air quality, harvesting of regional material, and disposal of waste. Buildings around the world affect the livelihood of all living species through their consumption of energy resulting to pollution and ozone depletion (O'Keeffe, Shiratuddin, and Fletcher 2009). LEED was used as the standard of choice due to its wide acceptance among the AEC/FM industries.

The author has developed a way to make GDL objects interoperable with other BIM software (O'Keeffe 2012). GDL model element objects are stock model elements native to Archicad. The GDL Reference Guide (Graphisoft 2009) can be used to learn novice scripting and modeling from scratch, or edit stock model element parameters in the GDL editor in Archicad and save it as a custom model element .gsm file format in an embedded library. It can then be used to export as IFC 2x3 TC1 to use in other software (Graphisoft 2010). This can eliminate the need to buy BIM model elements from third party proprietors to interoperate with software such as Revit. The custom model element can then be accessed to make copies and transfer the files to a database repository, e.g. a BIMserver, for efficient data management and harvesting of each BIM model element via the IFC file format.

GDL contains all the information necessary to completely describe building elements as 2D CAD symbols, 3D models and text specifications for use in drawings, presentations and quantity calculations, e.g. 4D and 5D BIM. GDL is also an intelligent model element object technology that offers a new and efficient way for building component manufacturers to market their products via Computer Aided Manufacturing (CAM), Internet, or CD-ROM, similar to the IFC product models that are shared in the same way. The GDL can become IFC upon IFC export from the BIM Software Application. The selection of building components during the design phase benefits both the architect, who can design using real-world objects, and the component manufacturers, who can provide product information to support the design process. As the infrastructure for digital communication grows rapidly, higher demands are raised upon intelligent 3D formats and catalogs for describing building components.

The GDL is a parametric object-oriented language and can create objects that are easy to access and easy to manage on the Internet. GDL-based electronic product libraries require little effort for their maintenance, which means it is easy to keep information on the website up-to-date. GDL objects can be used on both the Macintosh and Windows, and are able to export product data in the common Computer Aided Design (CAD) file formats including DXF and DWG and the emerging industry standard IFC.

The selection of building components during the design phase benefits both the designer, who can design using real-world objects, and the component manufacturers, who can successfully market their product at an earlier stage in the design process. This also leads to the opportunity of this information being reused for COBie, COBie2, SPie, LEED, IFC 2x4, etc.

Manufacturer's data are included in the GDL object information, which means product-specific information is available not only to the designer, but the facilities manager and all other building professionals who need access to such information throughout the building's life cycle. GDL is an IFC compliant open standard and easy to learn and use, so the initial development and maintenance costs are low. Additionally, data conversion is automatic, so there is no need to recreate information in different formats such as DXF and DWG, e.g. a GDL library repository on a web server.

An example of a parametric 3D BIM model element is a GDL object model that allows the input of created data into the model element parameters. Recent experiments by the author show that this information can be hard coded or developed utilizing a GUI. GDL allows the development of 3D objects via import from external model software. For this project 3ds Max was used as the modeling software of choice for the development of custom 3D models. 3ds Max was chosen by the authors for model creation because of its advance modeling techniques and Graphical User Interface (GUI), e.g. 3ds Max supports the export of curvilinear surfaces (NURBS), not to be supported by IFC until software developers advance the exporters to support the IFC 2x4 schema which applies NURBS and Manufacturer Data. Also, 3ds Max allows mesh modifications, which are straightforward via the GUI.

The newly created GDL model will retain all model information created and texture maps applied during the modeling phase. The author's graduate students have tested the round tripping of these IFC GDL LEED model elements in different CAD Publishers and the results show no loss of data via the IFC file format. The suggested process is to export a 3ds file from 3ds Max and open it as a GDL script in supporting software. One can use the 3ds add-on for Archicad that can be found on the Graphisoft web site. The 3ds add-on will allow the user to open the 3ds and save it as a GDL Object. By opening the script of the GDL Object, the user can create new model element parameters and export as IFC 2x3 TC1. Once the new model element parameters have been saved, the user can then open the model element settings and embed the appropriate cost, IFC, LEED, etc., information into the model element seen in Figure 7 (O'Keeffe 2012).

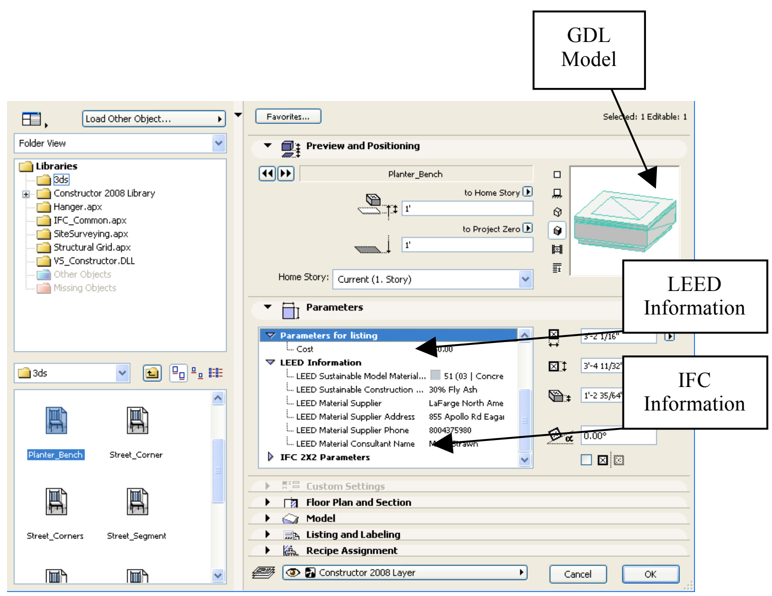


Figure 7. Custom GDL Model in IFC Compliant Software Application Showing a View of a GDL 3D Object Converted from 3ds MAX Modeling Software.

In Figure 7 the GDL model element is created and can then be used and added to the BIM. The importance of the GDL object is it can be used on the current project, reused on other projects because it is now in a database or library repository, and edited in the future if needed. Another rule of BIM is to not create anything more than once. In other words, "Do more with less" (Jernigan 2007 pg. 55). Figure 8 shows a prototype IFC BIM with custom GDL model elements that contain cost, LEED, and IFC information that allows the interoperability of LEED cost information in an IFC compliant software application.

The LEED IFC information was tested for IFC compliance. The Author used an open source IFC viewer and graduate student experiment that showed the LEED cost information relationship that can be used to estimate cost for LEED related construction projects, via the IFC viewer module application from TNO.

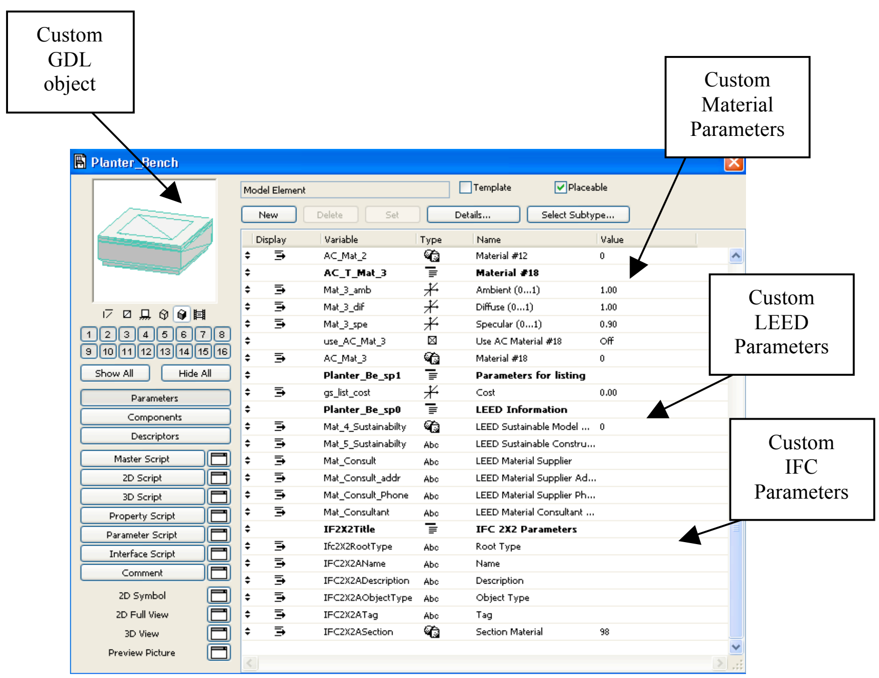


Figure 8. Custom GDL Script for Material, LEED, and IFC Parameters. The custom GDL Model in IFC Compliant Software Application Shows a View of a Custom GDL Script for Material Parameters, LEED Parameters, and IFC Compliant Parameters.

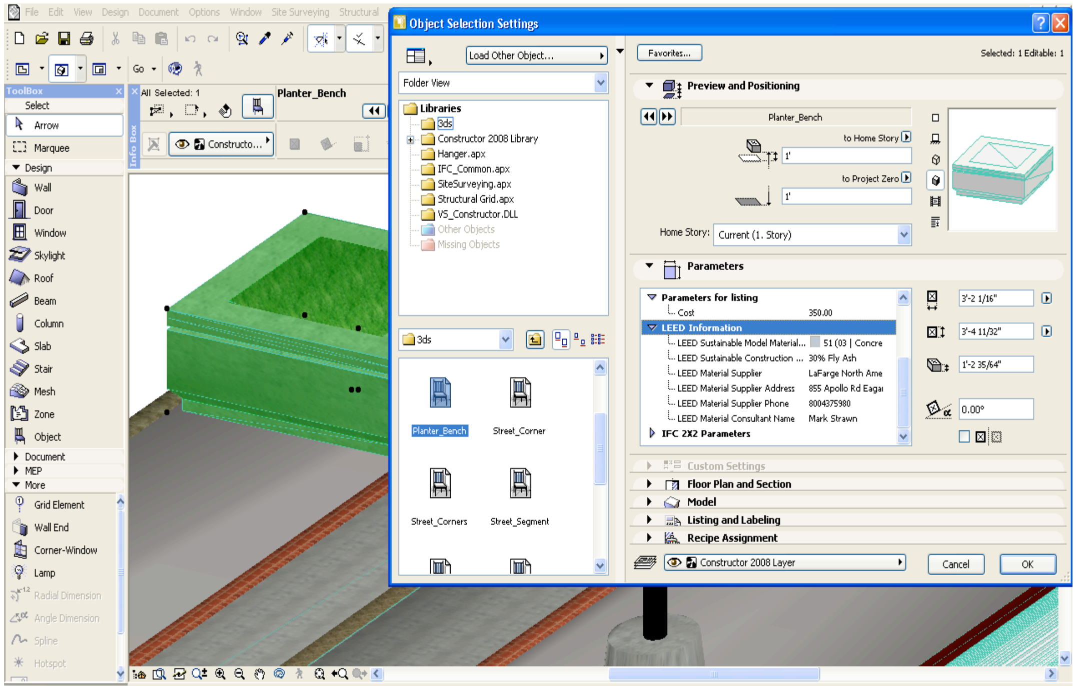


Figure 9. Custom GDL Model in IFC and LEED Parameters after GDL Script. The IFC Compliant Software Application Shows a View of a Converted 3ds MAX Model with Custom LEED Parameters After GDL Script was Created.

The Developed Web-based IFC BIM Software Utilizing the Developed nD Framework.

The USGBC (2007) has developed many useful rating systems for making healthier built environments, both indoor and outdoor. LEED is the name of the rating system and its guidelines. The nD BIM software application was developed using the 2009 LEED Version 3 for New Construction (NC) rating system, COBie for FM and Omniclass for industry product, material and labor classifications. LEED was used for the applications energy analysis, energy cost and design performance information in the development of the tool. The IFC is a platform neutral file format used by the AEC/FM industries when sharing model information during BIM. The nD BIM prototype allows BIM and IFC file format to share model project information and LEED information. Another challenge is LEED information embedded into a BIM is not a traditional practice. An IFC LEED Scorecard was developed to serve as an integrated LEED for NC checklist. The scorecard uses IFC Property Set Configurations, Figure 10, for the mechanism of the integrated checklist. Industry has shown the necessity to integrate the BIM and LEED information. This information is saved, shared, and reused. Round-tripping the IFC data through an IFC compliant CAD Publisher is how the validity of the scorecard was tested and the results show no loss of IFC or LEED checklist data ensuring the future reuse of the IFC BIM project data on future LEED projects. Figure 10 shows the IFC scorecard that can then be reused at future times to modify the checklist data to acquire a higher level of LEED certification and this stored data can also be used on other future projects. LEED certification in a virtual environment utilizes a BimServer, Figure 11, and bidirectional relational database. A web-based game engine, Figure 12, and the IFC BIM file are utilized to visualize the BIM and LEED certification process. O'Keeffe (2012) demonstrates that the bidirectional BIM workflow was designed using an open-source BimServer and game engine, database creating software, and IFC BIM CAD Publisher. Embedded and integrated custom IFC Property Set Configurations in Figure 10 allow industry to LEED certify the built environment in a virtual environment. The software database is also extended and contains the other nD dimensions such as COBie for FM and CSI's Omniclass classification standard. The software mentioned in this section only focus on the LEED standard, but also demonstrated is the visualization of the extended nD data from the nD database in a virtual environment.

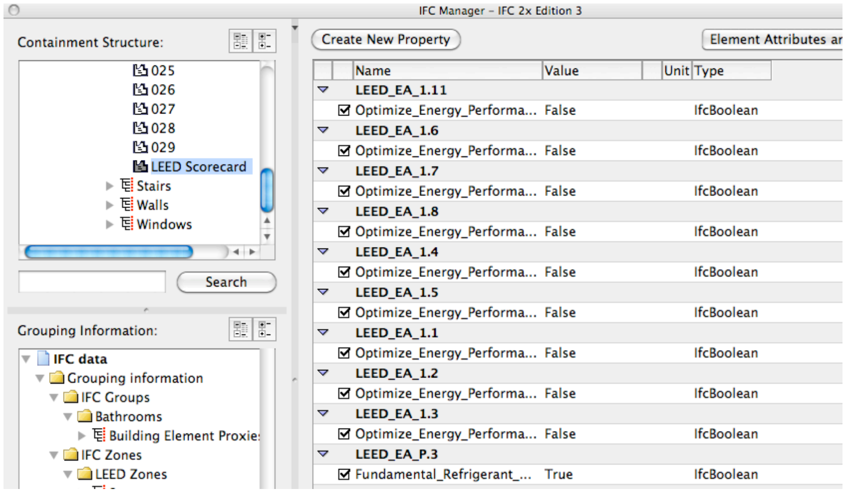


Figure 10. IFC Property Set Configurations for the IFC Scorecard.

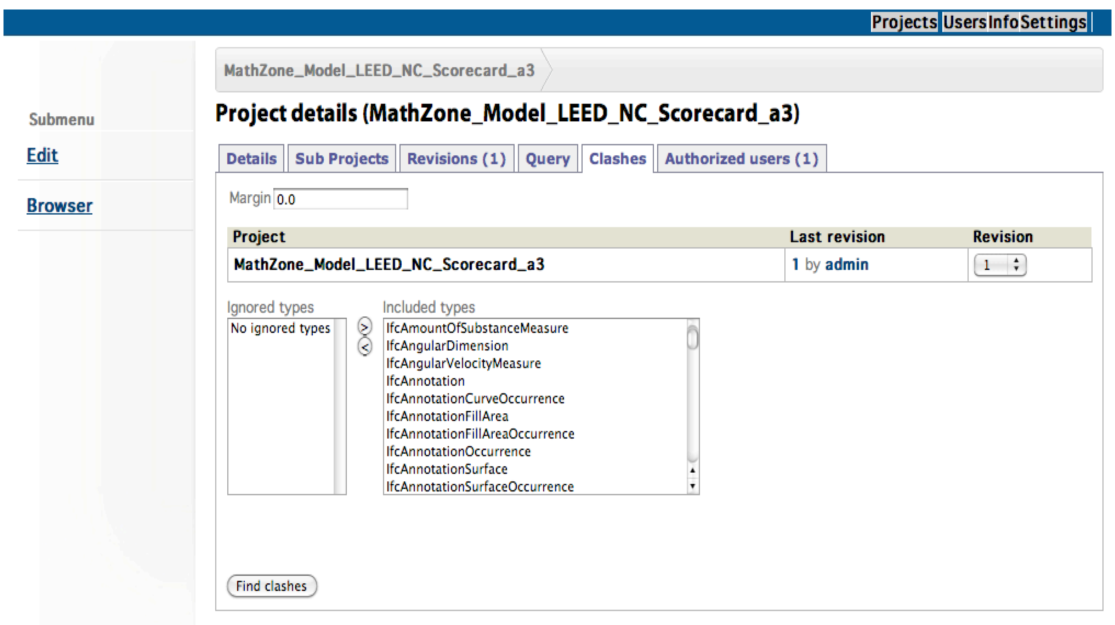


Figure 11. BimServer for LEED Certification in a Virtual Environment. Modified Open Source BimServer the location of the model repository.

Figure 12. nD BIM Web-Based Software Application Implementing the Developed 6D and nD Framework Utilized in Conjunction with the LEED Energy Standard Portion of the nD Database for LEED Certification Review Analysis of an IFC BIM in a Virtual Environment Linked to the BIMserver.

CHAPTER IV

6D FRAMEWORK, nD FRAMEWORK, AND nD ONTOLOGY CREATION

Developing the 6D Framework.

Now that we have discussed what BIM and 2D-6D are, it is time to go deep into the framework of the sixth dimension. The Integrated Definition Language (IDEF) was chosen to efficiently be very clear and communicate the sixth dimension framework, nD dimension framework and nD ontology. IDEF is a federal standard and was developed by the US Air Force as a modeling language to communicate complex new ideas meant for the manufacturing of advanced technologies. IDEF works like a set of construction documents and each page has indicators to other pages to prolong the development process in an organized manner. IDEF0 by National Institute of Standards and Technology [NIST] (1993) was chosen for this project because IDEF0 is for process diagrams and is intended for the communication of process business ideas. Microsoft Visio supports the import and export of IDEF process model; therefore, that was the software utilized to create the IDEF models in this doctoral dissertation. Business Process Model used for IDEF0, and the IFC schema in conjunction, is the starting point of the development of nD process diagrams for implementing nD properly at the beginning stages of the future development of nD BIMs (Smith and Tardif 2009). Energy, the 6th dimension within the BIM workflow, is a process; therefore it is feasible that the IDEF0 language be utilized for 6D…nD processes. IDEF0 is unique because once the model diagram has been created it can then be utilized for other purposes. An example is, if we are developing a robot, machine or software, the IDEF0 model can be exported as XML so that the programmer has less work and a clearer starting point for their software development endeavors. The process model for 6D energy begins at the highest level.

This level has the bare essentials needed to drive the new dimension input, output, control, and mechanism. When we begin to define the 6D framework, we first need an input, output, control, and mechanism. In Figure 13 it is clear that data of the built environment, one single BIM, is the input, IFC is the control, the database is the mechanism, and the output is one single model with one file type linked to a database containing energy informatics.

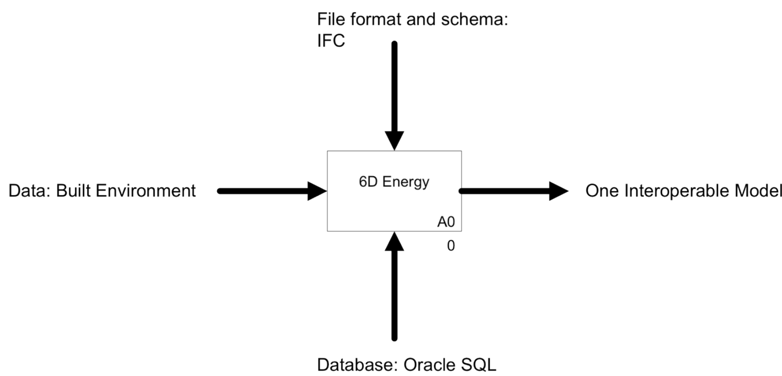


Figure 13. 6D Framework IDEF0 Process Diagram Schematic Level 1. The developed framework utilizing the IDEF0 language. The model shows the basic input, output, control, and mechanism needed for 6D. The input is the built environment data. The control is the IFC open source international standard file format schema that can contain the data for the whole life cycle of a project. The mechanism is a database repository that allows interoperability of the control. The output should always be a single IFC product data model that interoperates with all other dimensions. Refer to the Appendix.

In Figure 13 we can see that process one is labeled as A0. A0 leads us into the next process Figure 14. Figure 14 includes the various sub-processes necessary to finish defining and implement the sixth dimension. In Figure 15 A1-A4 shows the round tripping of IFC data for all dimensions including beyond the sixth. From A4-A5, Figure 15 shows, it can be seen that the output goes to a BimServer that serves as a central database repository for the holistic BIM. Also included are web-based functionality, virtual environment, and document exporter that is needed for the AEC/FM to be successful when implementing a multi-dimensional workflow process.

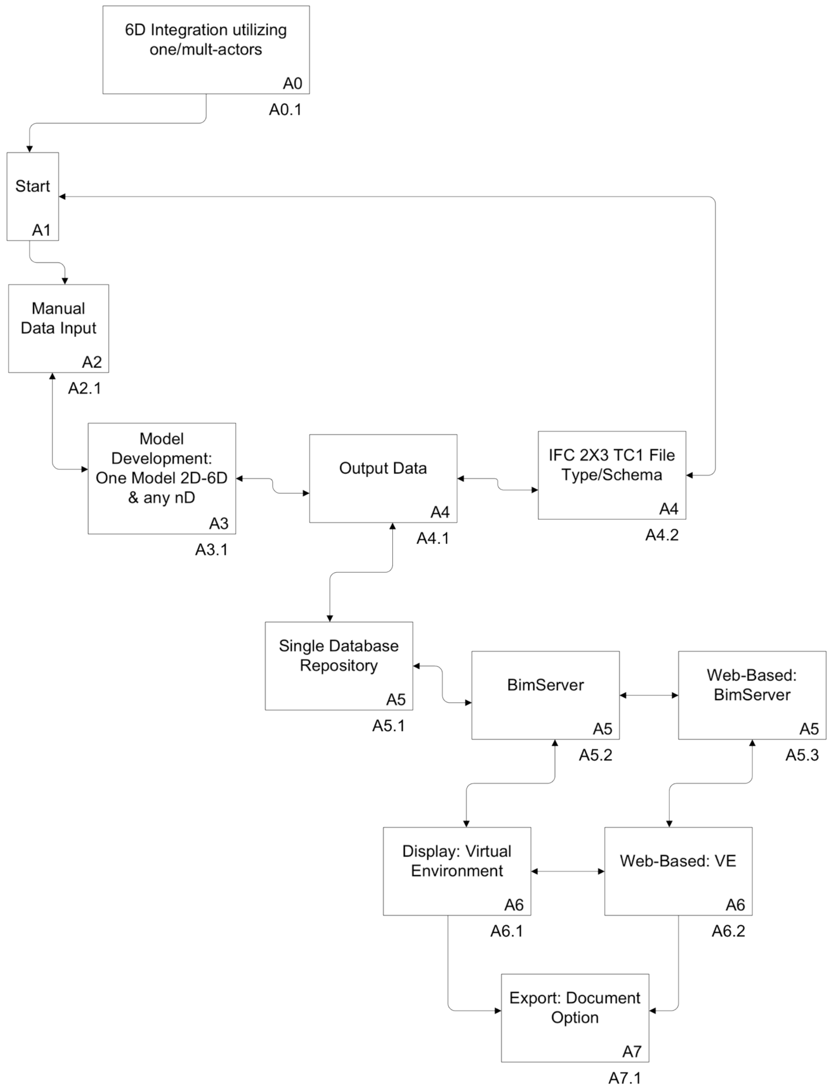


Figure 14. 6D Framework IDEF0 Process Diagram Schematic Level 2. The developed framework utilizing the IDEF0 language. It shows the second level of the framework needed for 6D.

Figure 14 shows the deeper complexity of the A3 process model development. It is necessary to go deeper into A3 because this is where the sixth dimension and future dimensions are located in actual application. Figure 15 explores the round tripping data of all dimensions utilizing one model and IFC schema as the one file type for interoperability among nD dimensions.

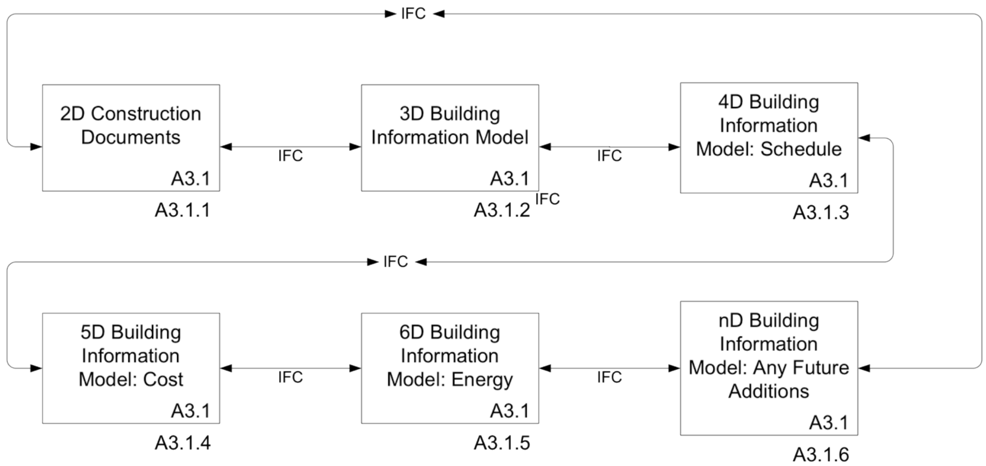


Figure 15. 6D Framework IDEF0 Process Diagram Schematic Level 3. The developed framework utilizing the IDEF0 language. Shown is the third level of the framework needed for 6D.

Developing the nD Framework

The nD framework utilizes an IDEF5 information model for object-oriented BIMs. IDEF5 was specifically designed to develop object-oriented processes (Benjamin et al.1994). Clocolu, Gruninger, and Nau (2000) also suggest ontology should be utilized for integrating engineering applications. To utilize the nD Framework one must create nD BIM tools, an extensive nD BIM database, visual analysis tools and web-based repositories that allows the query of all necessary information needed for nD BIMs, and legal process document export for global utilization. The IFC schema is used for interoperability of multi-dimensions for seamless data exchange. The IFC schema is designed to handle the querying mentioned above as discussed by Gu et al. (2008). Benjamin et al. (1994) explains IDEF5 uses the term ontology for the cataloging of rules governing how terms in a domain can be combined to make validity statements of situations in a given domain. IDEF5 ontological information models are the foundation for developing an nD process ontology mapping of events and definitions. Mapping of model elements via a relational database is needed for extraction and query of critical information during the utilization of nD dimensions when certain information is needed at a dependent stage point. Multiple dimensions such as energy, sustainability, safety, crime, accessibility, design review and facility management are some of the data to be queried and analyzed. Without the capability to query critical information on demand in real time, the tool is useless. Game engine custom virtual environment technology is an efficient method to create low cost solutions for the AEC/FM (O'Keeffe, Shiratuddin, and Fletcher 2008). Game engine technology is used to visualize the nD data in a virtual environment. The nD framework provides the foundation for interoperability among all nD dimensions by controlling all input and output data in a formal ontological methodology.

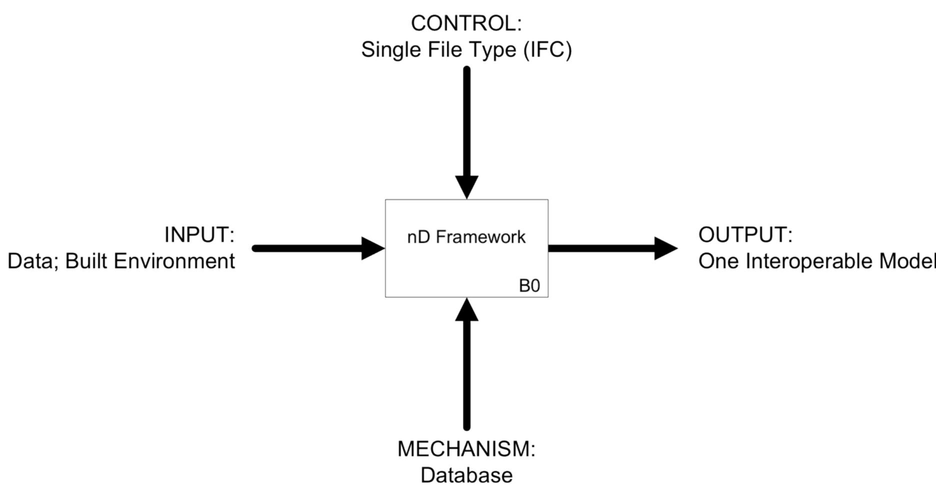


Figure 16. nD Framework IDEF0 Process Diagram Schematic Level 1. The developed framework utilizing the IDEF0 language. The model shows the first level of the framework needed for nD. The second and third level of the nD framework has the same process constructs as the 6D framework. That is why there is a synergy among the 6D and nD framework. Refer to the Appendix.

The nD Process Ontology

The conception meaning of information varies during communication. Therefore, communication can be hindered during the exchange of data (NIST 1993). The conception meaning of data is subject to the perception or interpretation of individuals. Ontology plays a very important role of clarifying data perception and interpretations by defining the relationships among kinds, and this is needed to identify the agents that commit to answer queries in a shared vocabulary (Benjamin et al. 1994). The dependency relation is if we have x information K', K is a sub-kind of K' due to information x, then both K' and K have different definitions with an x information relationship of the same domain (Benjamin et al. 1994). We distinguish the different types of K by their relationship to the K' domain when sharing x information. Ontology's provide the basis for explicit semantics versus just the use of perceived syntax. The intent of the nD Process Ontology is to combine the differences among process and product domains so querying the domain is precise and not ambiguous to the user. The purpose of the developed framework for 6D is that it can be utilized for any nD dimensional domain in the future, and this synergy is recognized when correlating Figures 16 and 19 that are synonymous in structural reasoning. The purpose of Figure 20 is to notice the distinguishable reasoning and difference between an nD abstract dimension and the clearly defined non-abstract nD dimension. nD = K' domain, and nD abstract and nD non-abstract = K subset domains. K' and each K share some x information. When querying x information, the user needs precise definition of x kinds. Without the ontology, such a query is not possible. Figure 20 shows the importance of specifically defining domains verses subset domains when querying is necessary. The importance in querying exists due to the fact domains and subset domains are queried utilizing a common vocabulary in which domains and subset domains exist. The nD ontology is a structured representation of query information. The relations of structured information are to be made explicit rather than left implicit to reduce misunderstanding of connections within a given domain containing x information. Ontology information in the IDEF5 formal language enhances the skill needed when extracting information x from the domain, particularly the extracting of abstract verses non-abstract x information in the domain (Benjamin et al. 1994). A key importance of the described ontology discussed is that when a formal language is utilized for object-oriented structures, the ontological information within the domain becomes reusable. Reusability is a concept needed for the AEC/FM to optimize the use of x information of nD BIMs. Without reusability, future BIM projects will suffer. Reusability allows stored domain x information to be extracted for future projects without recreating the domain information. One of the main concepts of BIM is to reuse the domain information on future project as much as possible (Jernigan 2007). Information used on one project should be able to be harvested from the central database repository for FM, future projects, and during the extending of dimensions as a project proceeds through its development of the project life cycle. The reusability of information in a domain leads to an enhanced understanding of that domain or time (Benjamin et al. 1994). The benefits of enhanced understanding of a domain are identification of problems before they occur, identification of problems causation, identification of alternate solutions in a domain, consensus for team building during solving problems, and reuse of the knowledge being shared (Benjamin et al. 1994). Other benefits are the ontology is a blueprint that can develop intelligent and integrated systems for information (Benjamin et al. 1994). Ontology is used as reference models for planning, coordination and controlling development activities, and support clues from the ontology that suggest high impact transition paths for process restructuring. Object-oriented design and programming are very beneficial because of ontological analysis and development of domains (Benjamin et al. 1994). If ontology methods are not utilized for nD BIMs, then there cannot be an organization and scope of dimensional activities necessary for defined domains, collect the domain activity for future reuse, properly analyze the reusable data, develop the necessary acquired data for reuse, and refine and validate the harvested ontological data. Utilizing IDEF5's object-oriented ontology language allows for the streamlined approach to creating relational systems, e.g. nD databases, for IDEF0 nD process diagrams. The ontology described in this section allows the domain information to be stored in a holistic centralized global repository as suggested by (Gu et al. 2008). As discussed in previous chapters is interoperability which one of the main goals of the BIM process and key to the round-tripping of data, especially utilizing defined non-abstract reusable data among nD dimensions at any time during the project life cycle and on current, past and future projects. Figure 17 demonstrates how the streamlining of IDEF0 process diagrams and IDEF5 ontology creation are semantically linked and the relationship of kinds is key when linking the two separate languages. Figure 20 is a formal IDEF5 language diagram to implement the relationship among kinds in conjunction with the prior IDEF0 process diagrams. The synergy among 6D, nD, and ontology of nD dimensional kinds in Figure 20 are discussed in the next section. Figure 17 is a second order IDEF5 schematic showing the defining of kinds. However, a first order IDEF5 schematic is not shown because it would only show K' = nD, which is irrelevant to the context of this doctoral dissertation because the purpose of this section is to show the relevance of kinds as they are applied to defining subset domains according to the domain in which they reside.

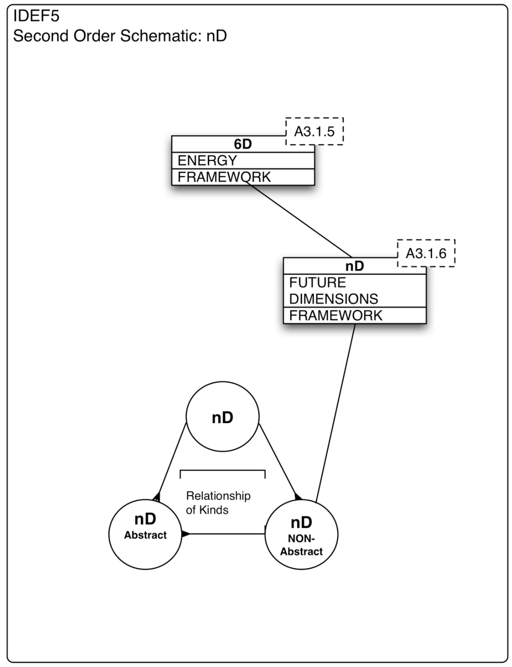


Figure 17. nD Ontology IDEF5 Process Ontology Diagram, Definition of Kinds. The process ontology diagram breaks down the new nD dimensions in the simplest form possible by showing the relationship of kinds. At this level is where the new dimensions utilize the ontological rule base system to distinguish abstract dimensions from non-abstract dimensions.

The Synergy of the Developed 6D Framework and the nD Framework

The 6D Framework does not *live* or exist without an ontologically defined nD Framework as an object-oriented IDEF5 process ontology for nD, and other dimensions cannot and should not exist if they do not comply with the developed nD ontology. The nD Framework and Ontology is a set of rules that can be applied to any AEC/FM dimension. The dimensions that currently exist are cumbersome and vague in understanding the perception of the true intent of integrated processes. Let us analyze this to be very clear and complete. The nD Framework and Ontology consist of an input, control, mechanism and output, which is formulated using IDEF0 and IDEF5 formal languages. These four semantic rules are to apply to all new dimensions for the future of the AEC/FM. The input must be analyzed to contain the most accurate information available for a given project specifically utilizing one BIM that uses the IFC schema. BIM practices allow all stakeholders to communicate early during planning so the input information must be accurate (Jernigan 2007), this is the intent and purpose of early collaboration among stakeholders when implementing the BIM process. The input is technically the initial project model data, which will be built upon during the expansion of the BIM dimensional process when developing a BIM of the built environment. The second semantic rule is the control. We must control our data utilizing a single file type so congestion among data interoperability during the use of BIM tools and data collaboration among stakeholders stay organized and concise and do not become lost or unable to be queried when needed. The most widely used standard to openly exchange model data is the IFC file type and schema (International Alliance for Interoperability [IAI] 2011). IFC as a control allows the ability to contain all project data in a single file using a single EXPRESS ISO standard schema and is considered to be the product model data repository. The IFC schema is the current control utilized by the nD framework. It is also possible that the control may change in the far future, but this is very unlikely due to the globalized recognition and legal document process usage of the IFC schema. If, and only if, the IFC fails the test of time, the AEC/FM shall convert to some other format as long as it has the capability to out perform the IFC schema architecture. This is very unlikely to happen since academic researchers have spent many decades developing and preparing for the IFC paradigm shift, and the IFC has taken the place of all other formats that have been developed for the AEC/FM since the early 1970s. The ultimate goal of the control, as a semantic rule, is to use just one file type for all project data because this increases interoperability performance, optimizes computational power and allows the possibility of round-tripping and querying a single product data global repository noticeable in Figure 14 above. The intention of the development of the IFC schema architecture when the IAI and MSG developed it was to create a universal international schema for the interoperability of object-oriented parametric product data models during the utilization of the BIM process in all AEC/FM industries. The mechanism that ties the input, output, and control together is a holistic relational database specifically designed to allow bidirectional interoperability among dimensions when using a single data model and single IFC schema.

CHAPTER V

FUTURE WORK

A Future for nD BIMs

Algorithm for Computing the Validity of New nD BIM Dimensions

An algorithm will be designed for validation of new nD dimensions. The author will show that the new nD must fit the nD framework and the nD ontology to compute the new nD dimension and it is not an abstract dimension. The AEC/FM needs non-abstract dimensions as discussed in Chapter IV. New nD dimensions can be validated, in theory, by computing a probabilistic algorithm that shows if a new nD is abstract or non-abstract. First the variables for the input, output, control, and mechanism for a new nD dimension is needed to be defined as in Chapter IV. Then, denote that input A is the BIM Built Environment, which is an IFC BIM singular parametric data model. The control B is the IFC schema. The output C is the single IFC BIM model. The mechanism D is the database that is linked to a distributed relational database repository locally and on the Internet. If A, B, C, and D are defined in this manner, then dimensions 2D to nD is the sum of i = 2D to nD. Next, ABCD must be defined as a new variable F representing the framework. If the new dimension fits the constructs of the framework, then the probability of the new dimension can be calculated to show that the new dimension is non-abstract. Also, the non-abstract dimension can then utilize the nD process ontology to define kinds within the new dimension based on the kinds rule based system. The non-abstract dimension will then be integrated into the BIM workflow. Academic researches in the area of the AEC/FM should realize the empowering effect of specifically defined dimensions and how it benefits all stakeholders. This algorithm will be a way to reduce conflict, improve interoperability and collaboration, and keep the BIM workflow from becoming stagnant. Therefore the BIM will not die and at will continue to provide reusable data for the AEC/FM. To reuse data is to not recreate the wheel. This is key to successful implementation of the BIM process.

Semantic Free Referencing in nD BIM Database Systems

Semantic Free Referencing (SFR) may be an additional methodology for the nD database system technology that could enhance computational power in large scaled BIMs. The goal is to reduce the unnecessary use of space that syntax with semantics intakes. Words without semantics in a database system can save space and computational power when querying. Currently, when querying the relational database, words with multiple meanings must be redundant. These words exist in many forms with several semantic attachments. SFR in an nD database would allow words with multiple meanings to exist once and then be directed to the appropriate locations. For example the word rock has many meanings and therefore must exist many times, but if SFR is utilized then the word rock has no semantic attachment and can exist only once in the database structure. When a sentence containing rock is queried, and each *r, o, c,* and *k* will be directed by a mobile agent to the appropriate location independent of semantics.

Multi-Agents in nD Database Systems

Multi-Agents in conjunction with SFR is the key to directing the path of syntax that utilizes SFR. SFR alone cannot accomplish the task needed to reduce computation of large scaled nD BIM databases. Semantic Free Reverencing must have a method of navigation. The importance of the Multi-Agent is to navigate the syntax when using SFR. The Multi-Agent architecture technology allows domain specific information to be distributed among integrated systems.

The nD Framework and nD ontology Utilized for Virtual Supply Chain Systems.

Describe is a virtual integrated web-based collaboration platform for supply chain systems. Demonstrated is the benefit of an integrated approach from the seamless exchange of information for manufacturing, procurement and supply. A bidirectional approach is utilized for the exchanging of information among platform users. Recent studies of Building Information Modeling (BIM) show benefits of integrated practice including waste reduction, shorter project duration, and cost savings. Such an approach provides a broad array of opportunities for improving decision-making. A central database repository is the foundation for bidirectional information sharing. The Industry Foundation Classes (IFC) schema/file type is used for the interoperability of supply chain information. The IFC files will have a direct relationship with a database to build a feasible collaborative platform. Collaborative platform allows the querying of IFC information for suppliers and manufacturers for seamless exchange of information without loss of data. Round-tripping data with no loss during bidirectional exchange is the main objective to validate the research. The main benefit of collaborative platform is the automated process of ordering, scheduling, manufacturing, distribution process in a supply chain. In addition, the IFC file type allows real time 3D visualization of all data as geometry. Building Information Modeling (BIM) is benefiting all AEC/FM industries in many aspects of their practice. The vision is possible implementations of BIM for supply chain. BIM is a beneficial process of integrated practice in industry that comes from the 1960's European automobile manufacturing. The process of an interoperable integrated practice for the AEC/FM is BIM. BIM is unique to each individual practice (Jernigan 2007), but an individual's BIM must remain interoperable with others BIMs. The above statement will also apply to the utilization of BIM for supply chain. Discussed is an integrated web-based collaboration platform for supply chain systems. To be more specific, the collaboration platform is an open source BimServer from BimServer.org. One can utilize the BimServer for many different purposes and the idea for supply chain is much like the developed nD BIM LEED Certification Software for the United States Army Corp in the next section of this chapter that utilizes a BimServer as the interoperable *hub* for information query. This approach is accomplished by querying IFC files for relative data. However, how one uses integrated practice, BIM for supply chain, determines the benefits the user will receive.

In this research, Archicad was chosen as the BIM tool for creating the BIM for supply chain because of its robustness and quality control of IFC data during the design of the BIM parametric model. Figure 10 shows an example of a BIMs model element, opened in the IFC Manager, to show the Psets and how they are flagged prior to export as IFC 2x3 for interoperability with the database and BimServer. The objects data shown in Figure 10 are the exact data that is in the IFC file after export. This is the data queried for supply chain purposes. Psets for Manufacturer, Packaging, and Cost, just to name a few. The Psets are actually endless due to the ability to create any new Pset’s needed for supply chain that is not supplied by the CAD Publisher by default.

The implemented design has a centralized BIMServer on which to host the IFC files of the project for querying and version control purposes. The BIMServer is a powerful tool dedicated specifically as a version controlling central repository. The repository caters to the unique properties of IFC files, which allows the querying of IFC data. Installing the BIMServer is as simple as running a .jar file. However, because the BIMServer acts as a server the user must have a static IP Address, have an open port with default port of web pages 80, and make sure no firewall is blocking it. Any difficulties that arise in this stage should be directed to a network administrator, as network configurations vary. An administrator can direct or assist in meeting the requirements for your specific network.

Logging in to the BimServer is straightforward. The utilization of admin for both username and password are included in the server settings and can be edited and saved. Once logged in, adding a new project is also a simple task. Under the "Projects" tab at the top of the BIMServer page, clicking on "Add Project" on the left panel will allow to create a project (Fletcher et al. 2011). Keep in mind that new projects are empty and the BIMServer will warn accordingly. Any new project must have a file uploaded to it before it is of any use. This can be accomplished by going to the "Revisions" tab. Simply click "Browse" then after locating the IFC file you wish to upload click "Upload." This will begin the uploading process (Fletcher et al. 2011). Upon completion of the upload process the BIMServer will automatically populate the project revision at the bottom of the current tab. If the wait icon at the bottom of the revision does not go away after the upload is complete you can check on its status by refreshing your browser. Since the IFC file can come from any source, it is recommended to use the latest version of ArchiCad as it is compatible with user generated property sets, which are recommended and does not appear to lose any data when round tripping your data between applications. Archicad and the BimServer have a one-to-one mapping of data utilizing the IFC 2x3 TC1 schema.

Archeology Domain for a new nD BIM Dimension

Archeology can benefit a great deal from the unified nD BIM framework and nD BIM ontology model in conjunction with pattern recognition algorithms. The unified nD model can be utilized to construct an As-Built BIM for historical preservation of archeological sites such as the Abu Simbel Temples, Valley of the Kings, and Inca

Architecture. The nD As-Built BIM for archeology in conjunction with pattern recognition algorithms is the author's proposed idea to preserve archeological sites on a global scale. As-Built nD BIMs will be a common practice in the future. An As-Built BIM is a BIM that includes all information during the design and construction project life cycle. The As-Built BIM is created at the end of the construction project to insure facility management (FM) is possible to continue the restoring of the building and built environment over time. Common knowledge shows that buildings and the built environment deteriorate over time. Some built environments deteriorate faster then others depending on variables such as materials and climate. As-Built BIMs are also commonly modeled after buildings have been built because the technology used to create BIMs did not exist at the time. This fact leads to the idea that the unified nD model philosophy can be utilized to preserve even the most ancient structures on the planet. Pattern recognition algorithms can assist the nD As-Built BIM once the nD BIM is created of an ancient structure like the Abu Simbel Temple. A pattern recognition algorithm can detect the decay of ancient structures. If an As-Built nD BIM of the ancient structure is created, then from that point on the preservation of the ancient structure is possible. The As-Built nD BIM will contain all the current structural information in an nD database. The nD database, in conjunction with pattern recognition algorithms, will allow the querying of the structural decay data via a central web-based repository. The repository is the central location of all As-Built nD BIM data.

CHAPTER VI

CONCLUSION

The future of BIM for the AEC/FM is promising. Yet, the industry still has many obstacles to overcome. The main obstacle is the adoption rate of the new technologies needed to implement BIM. Unfortunately, the USA is behind the rest of the world, as a whole, in the adoption process. The good news for USA is they are persistent in the endeavor to learn more about BIM and utilize the BIM process to enhance their revenue and become globalized in the new paradigm. It has taken many years to get the USA in the race of globalized BIM. The USA as a whole is now realizing the benefits of BIM because many of the early adopters are now showing their progress of beneficial rewards BIM allows for AEC/FM firms. BIM is not an easy concept to get a hold of, but once the multi-dimensional interoperable journey BIM is now on is in the grasp of the AEC/FM, the benefits become endless. BIM is an integrated process unlike the previous paradigm of the traditional approach. It is normal to have such a huge learning curve in the new paradigm of BIM. The old ways are becoming quickly flushed out when many new scholars are constantly entering the workforce. It is life taking its course; the new ways replace the old. Soon, BIM will be the only practice for the AEC/FM. Humans would not have conducted missions in space nor planned adventures to the moon or mars if integrated processes did not work. We also would not have automobiles for all humans if integrated processes did not work. Integrations of new technologies are cumbersome, and interoperability is not easy to understand. The mentioning of dimensions for the AEC/FM is also a very new concept and is hard to fathom for the older generation. Without much knowledge in the computing area, AEC/FM firms do not conceive the working constructs of the interoperable multi-dimensional approach. They seem to think it is magic when they utilize the BIM software tools and do not realize the complexity of the underlying algorithms that make interoperability feasible to them. Understanding BIMs down to 1's and 0's as a computer scientist is the approach to control ones BIM. The more we educate the AEC/FM that the BIM process is not magic and that there is a way to control everything they do, their work practices will become less hectic in the workforce. At first, the AEC/FM thought BIM would reduce the traditional jobs and many of the long-term experienced personnel would lose their jobs. This is the crux of the AEC/FM unwillingness to adopt BIM. Over the past ten years AEC/FM have been realizing BIM actually creates thousands of new jobs and the traditional experienced personnel have job security due to the fact they are still responsible for the usage of data in the legal processes and not the creation of the data under the new BIM paradigm. Firms are now working together and sharing data under new contract concepts such as Integrated Project Delivery (IPD) and Design Build (DB). The USA government is now turning to these new contract concepts because of the tremendous benefit brought to the table when they are utilized properly. The key to success is to utilize the contract concepts and technologies in harmony wisely. If a firm is uneducated in the working constructs of the BIM process and jump right into it, they set themselves up for failure. Sometimes failure is a good thing. Failure brings about learning, knowledge, and wisdom as long as they continue to persist.

Some of the information in this doctoral dissertation is futuristic, but some of it is on its way to being implemented in today's workforce practice of the AEC/FM. It is up to the researcher in academia to continue to develop the new paradigm of BIM. Some firms have hired their own researchers and software developers to stay ahead of the conservative norm of the AEC/FM industries. This is also normal. Top businesses want to stay on top once they have grasped and received the beneficial rewards of BIM such as large returns on investment (ROI) of projects when properly implementing the processes. These tremendous ROI's bring about the incentive that the conservative norm sees when deciding to adopt. Many firms are now consulting with the software developers of multi-dimensional BIM software so they can learn to eventually do it themselves. 4D and 5D are high on the rise currently in the AEC/FM, and other dimensions like energy and facility management are being used more and more each day. Other countries are even going much further and indulging in the benefits of other dimensions such as sustainability and crime prevention by the utilization of BIM object-oriented parametric data models.

In order for the world to benefit from the BIM process, they will need to utilize a common framework. An nD framework is developed to help the world proceed in their shortcomings and move forward in the BIM paradigm shift. One single framework that shows the utilization of one schema and one object-oriented BIM, linked to a database repository, will allow the sharing of data seamlessly among stakeholders in the AEC/FM. Then the data can be round tripped and recycled for reuse on future projects or during the maintaining of the old ones. When data is not centralized, the sharing of data in a holistic manner is not feasible. The AEC/FM needs rules to accompany the framework so all stakeholders are on a common page in the workforce when collaborating and communicating about the multi-dimensional data. Therefore, nD ontology is created. If the AEC/FM continues to try and practice without defined dimensions it will continue to have the large learning curves and unwillingness to adopt. People need a road map when trying new things. If we did not have a common road map for semantics we would all speak of nothing. Syntax has no meaning when the semantics are not defined. Without a direction there is nowhere to go. Information here in this doctoral dissertation is key to overcoming the problem of large BIM datasets and the sharing of the data to correctly implement BIM on a global scale. Parallelization is key and many other industries are utilizing parallel algorithms to overcome the same problems that are soon to occur for the AEC/FM when utilizing BIM on a global scale. We can object-orient the world for a better future, but one cannot do it by oneself. The new contracts being utilized by the AEC/FM are forcing the sharing of everyone's data throughout the whole life cycle for the project. This is new to them. In previous times, no one shared any data and kept it to himself or herself locked away in file cabinets with not much future reuse by the whole team of stakeholder involved. When sharing data on a global scale, with all sharing a common goal, a framework and ontology is needed. To do it without will only bring about the same chaos that exists now. Everyone agrees recreating the wheel everyday is not the best methodology one can think of. An object-oriented parametric product data model of a wheel that can be used over and over again in the reuse of creating a wheel when one is needed is much wiser. We shall see what the future has in store for the AEC/FM. Here it is stated the future is bright and promising for the AEC/FM as long as data is recycled and shared wisely.

APPENDIX

UTILIZING THE 6D FRAMEWORK FOR ENERGY INFORMATICS

Input – Construct 1 of the IDEFO 6D Framework

The 6D Framework consists of four constructs. The Input is most critical for the user to maintain and construct the 6D dimension properly. The Input is actually an IFC BIM that is prepared for the utilization of the whole building life cycle. Making sure that your BIM can be utilized for design, construction, and facility management is a main philosophy of BIM. Only, this type of BIM shall be the built environment (BIM) input for the 6D Framework. If the BIM is not constructed in this way the 6D Framework will not be feasible.

Control – Construct 2 of the IDEFO 6D Framework

The control is important due to the fact it is the schema that allows interoperability among all dimension. IFC is chosen as the schema because it is the global standard utilized by BIM software developers for interoperability among BIM tools and query of critical information during the life cycle of the construction project and the built environment. The IFC schema architecture allows the querying of information via IFC classes that are mapped to the object-oriented parametric product data model. A BIM can exist as just an object-oriented parametric model, but then it would not be an IFC BIM that is critical to the control construct of the 6D Framework. The object-oriented parametric product data model is an IFC BIM that can be utilized through the whole building life cycle including the fabrication of the BIM during construction hence this is why an IFC BIM is called a product data model. The IFC BIM code is read by machines and software to produce the real world construction materials needed for construction and, that then on site can be used to erect the building during the process of construction and the delivery of construction materials. If the control construct is not an IFC BIM, then the 6D Framework will fail.

Mechanism – Construct 3 of the IDEFO 6D Framework

The mechanism is just as critical as construct one and two. The mechanism is a holistic database repository that contains the information for all dimensions and especially the 6D Framework construct one and two energy information. The database recommended by the author is an Oracle SQL database that can be used to harvest data via query utilizing Ifc classes. The query of the database shall be conducted via IFC classes for object elements in the BIM. The database must exist to use the 6D Framework energy theory. If there is no relational database system, then there is no way to query in real time IFC energy information needed to supply stakeholder on demand. The significance of the relational database is that it allows synchronization among all dimensions in a BIM workflow. A BIM workflow is defined as how the user utilized interoperability among IFC compliant BIM tools.

Output – Construct 4 of the IDEFO 6D Framework

Construct four shows the validity that the construct processes of the 6D Framework were implemented properly, if the output shall be one single IFC BIM linked to a relational database system, and allow all object oriented information of the BIM to be queried via the IFC classes from the database system. The significance of the output is that it allows for future dimensions to be added to a BIM workflow in the future, and the synchronization process happens when information is changed in one dimension it is then reflected in all dimensions.

The nD Unified Model – nD Framework and nD Ontology

A nD Unified Model for Future nD Dimension

The author would first like to point out the synergy among the 6D and nD Frameworks. The synergy of the frameworks is they both share the same input, control, mechanism, and output. The author uses this synergy to show validity of the nD Framework for future dimensions and the use of the nD Unified Model in other industries. Although the nD Framework provides a mechanism for future dimensions, the question arises about the naming convention of new dimensions for the AEC/FM. Therefore, nD Ontology was created as the second portion of the nD Unified Model. The nD Unified model consist of both the nD Framework and the nD Ontology.

The nD Framework

The nD Framework follows the same constructs as the 6D Framework. Refer to the section above for the creation of new dimensions in the future. The input, control, mechanism, and output are the same for nD dimension as they are for the 6D dimension. The main objective in the creation of a new nD dimension is to define the new dimension according to the nD Ontology.

The nD Ontology

The nD Ontology allows the creator of new nD dimensions to specifically define the new dimension according to the structural relationship of kinds the object-oriented IDEF5 ontology provides. The AEC/FM needs properly defined dimension to integrate new dimensions in an interoperable IFC BIM workflow. The IFC BIM workflow will be disjunctive if the new nD dimension is not defined according to a structural rule based ontological system. Therefore the nD Ontology must be utilized when developing new nD dimensions. The purpose of the nD Unified Model is to insure all new nD dimensions are interoperable via the control construct the IFC schema. If a developer of new dimensions only uses the nD Framework and not the nD Ontology in conjunction with the nD Framework, then the new nD dimension will fail in regards to interoperability, database connectivity, and the one single model IFC BIM output construct of the nD Framework. Also, the problem of stakeholder collaboration will still exist. The significance of a nD Unified Model is to insure proper interoperability among nD dimensions and clear and concise collaboration between AEC/FM stakeholders.

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