MODEL-BASED AUTOMATED VALUE ANALYSIS OF BUILDING PROJECTS

Nora El-Gohary, Assistant Professor, gohary@illinois.edu
Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign, Urbana, Illinois, USA

ABSTRACT

Axiology is a theory about values and value measurement. Axiology addresses two key questions: (1) What are the ‘things’ that we value? (What is of worth, merit, utility, or importance?) and (2) How do we measure the value of the ‘things’ that we value? Axiology-based construction is defined in this paper as a theory-based approach–which is both holistic and formal—to the planning, design, and construction of buildings and infrastructure systems that accounts for human (clients, stakeholders, etc.) values. In this context, ‘value’ is viewed as a complex concept that carries rich and varied meaning depending on the type of value being considered (economic, environmental, social, technological, ideological, etc.) and the assessor of the value. This paper focuses on introducing the theory and method of axiology-based construction of building projects. The approach for axiology-based building construction entails two steps: (1) developing a formal (computer-understandable) axiology for building projects and (2) integrating the axiological model with the building model (the Building Information Model (BIM)). The formal representation, along with the integration with BIM, will facilitate the automation of the value analysis process. The paper starts by introducing axiology as a science for value analysis. Then, the paper presents a preliminary axiological model for value analysis of building projects. Finally, the paper discusses the framework for integrating the axiological model and the BIM model.

Keywords: value analysis, axiology, BIM, knowledge modeling, model-based construction management tools and systems

1. INTRODUCTION

Value Engineering (VE) has been implemented for years within the construction industry as a technique for improving the value of building projects. However, VE is mainly a function-focused analysis that expresses value as a ratio of function to its cost (Kelly, 2007). The key purpose of VE is to accomplish the essential functions at the lowest total cost, consistent with the required levels of performance and quality. From a more holistic perspective, “Value” is a more complex concept that carries rich and varied meaning depending on the person perceiving the value and the type of value being considered (economic, environmental, social, technological, ideological, etc.) (Barima, 2009; Alves et al., 2009; Dewan and Smith, 2005; Mukherjee and Muga, 2009; Ormazabal et al. 2008). “Value” is the worth, merit, utility, or importance of something – it is not just a relation between “function” and “cost.” Existing value analysis approaches (such as VE) have, thus, in reality, been focusing on “function” and “cost,” rather than “value.” Therefore, we need to better define, model, and reason about “value” – in its complex and holistic sense – in order to better analyze and improve the value of our buildings. In the context of building construction, we need to define what are the ‘things’ that we value in our buildings, how do we measure the value of these ‘things’ (i.e. how to do the valuation), and how to account for those values during the planning, design, and construction of our buildings. We need a holistic and formal model to assess the value of building projects.

To address this need, this paper introduces an axiology-based approach for building project value analysis. Axiology is a theory about values and value measurement (it is a science of value). Axiology addresses two key questions: (1) What are the 'things' that we value? (What is of worth, merit, utility, or importance?) and (2) How do we measure the value of the 'things' that we value? An axiological model can thus be defined as a model for value representation and value measurement. The proposed axiology-based value analysis approach entails two core elements: (1) developing a formal (computer-understandable) axiological model for building projects – a model for representing and reasoning about building project values and valuation in a formalized and holistic way; and (2) integrating the axiological model with the building model (the Building Information Model (BIM)). The formal representation, along with the integration with BIM, will facilitate the automation of the value analysis process. The integration with BIM creates an opportunity for enriching building information by adding information about the values of building objects and how these values are measured based on building project properties. This would result in improved information for making decisions and, consequently, a better understanding of how the planning and design decisions increase or decrease the value of our buildings.

The structure of this paper is as follows. The paper starts by a section introducing axiology as a science for value analysis. Then, the following section presents a preliminary axiological model for value analysis of building projects. Finally, the paper discusses the framework for integrating the axiological model and the BIM model.

2. AXIOLOGY: A SCIENCE FOR VALUE ANALYSIS

'Axiology' is a science of value. The term 'axiology' is derived from the Greek word 'axios' meaning worth or value. Axiology explores the questions of how to define the types of values and how to measure these values (Smith and Thomas, 1998). Formal axiology is a branch of axiology that was introduced and developed by Robert Hartman. Hartman (1967a, 1967b) identified the hierarchy of value and formalized the science of axiology (or the value science) - the science of how humans make choices or value judgments. He introduced value mathematics as a means for measuring values in an objective manner. In the remainder of this section the author will provide an overview of the key notions in Hartman's value theory. The author will attempt to present these notions in a simplified manner and will add examples relevant to the building domain.

According to Hartman (1967a, 1967b), value is defined as a "formal relation, namely, the correspondence between the properties possessed by an object and the predicates contained in the intension of the object's concept." Here, the properties of the concept are called 'the predicates contained in the intension of the object's concept'; and as such, for simplification Hartman's definition can be paraphrased as follows: the value of an object depends on the extent to which its properties correspond to the properties of its concept. In other words, in order to determine the value of an object, we need to compare the properties actually possessed by the object to the properties that are used to characterize the object's concept. For example, the proposition 'this chair is good' means that this particular thing is called 'chair' and it has all the properties connected with the concept 'chair.' More precisely, it means that this thing is a member of the class of chairs; and the class of chairs is defined by the concept name 'chair' and is characterized by certain properties; and this particular thing called 'chair' has all the properties in question. So, according to Hartman, a good thing has a concept name, that concept is characterized/defined by a set of properties, and that thing possess all of the properties in the set.

Hartman (1967a, 1967b) established the principle that each property of the thing is worth as much as the other, depending on the level of abstraction. Thus, a thing will be more valuable the more of the concept's properties it has, and less valuable the fewer of the concept's properties it has. For example, if the concept 'chair' is characterized by 3 properties (knee-high structure, seat, back), then a chair which has no seat is not a good chair but a bad chair. Based on that, Hartman defined four basic value terms to be used as a measure of value: "good," "fair," "average," and "bad." If a thing has a finite set of n properties, each of them is on the same level of abstraction, then, a thing is 'good' if it has all of the n properties, 'fair' if it has more than n/2 of them, 'average' if it has n/2 of them, and bad if it has fewer than n/2. Words such as good or bad are basically words of measuring value, similar to other measuring words such as 'kilometer' (word of measuring length). These four basic value measures, thus, can be extended to include other measures, such as 'poor,' 'deficient,' 'excellent,' etc. They can also be converted to numerical values. As such, according to formal axiology, to measure the value of an object, we must get to know its properties (or attributes), apply an ideal standard to it, and determine the degree to which it measures up to the elements of that standard.

Hartmen (1967a, 1967b) introduced three basic dimensions (types) of values and valuation:

- Systemic things and systemic valuation: A systemic thing cannot be either good or bad; it can only be or not be that such thing. Geometric circles, triangles, numbers, are examples of systemic things (a thing is either a circle or not a circle – there is no good or bad circle). The values related to systemic things (concepts) are called systemic values – they are either completely fulfilled or completely unfulfilled (perfection or no perfection). As such, as systemic concept has a finite number of properties that are used to characterize that concept. If an object lacks one single property of the concept, then it has no value. If a circle lacks one single property of the concept "circle" - which is "a plane closed curve equidistant from a center" - then it is not a circle. Systemic valuation is a rigid valuation in terms of conformance to a system or a formal construct (e.g. conformance to a regulatory system or conformance to the definition of circle). Systemic valuation, thus, sees things either black or white (a thing is a circle or not a circle, a person is complying with the law or not, the information is correct or not) .
- Extrinsic things and extrinsic valuation: An extrinsic thing can have axiological values of goodness, badness, etc. Everyday objects - such as chairs, tables, cars, walls, buildings - are examples of extrinsic things (e.g. a chair could be good or bad). An extrinsic thing has potentially an infinite number of properties, but in practice extrinsic valuation will be based on only a few of these properties. Extrinsic valuation is a flexible valuation in terms of practical aspects, such as functionality, economics, etc.
- Intrinsic things and intrinsic valuation: An intrinsic thing is unique thing; it is incomparable and irreplaceable. Anything of a spiritual or personal value could be intrinsic (my child, an antique chair, a piece of art, etc.). An intrinsic thing has an infinite number of properties. Intrinsic valuation is an emotional valuation in terms of personal judgment, spiritual aspects, aesthetics, etc.

Thus, any 'thing' (whether it is a systemic thing, an extrinsic thing, or an intrinsic thing) can be valued systemically, extrinsically, and/or intrinsically. Based on these three dimensions of value, Hartman developed the hierarchy of value and applied set theory to the set of properties of a concept. Set theory is a kind of mathematics that deals with the relationship of sets and subsets. This resulted in what is called the 'value mathematics.' The overview and discussion of the value mathematics is beyond the scope of this paper and will be presented in future work.

From the above-mentioned overview and examples, it can be argued that:

- Properties versus parts: Hartman refers to parts (back of chair, seat of chair, etc.) as properties. It can be convincingly argued that the back of a chair is actually a part of the chair, not a property of the chair. Similarly (speaking of buildings), the wall is part of the building, not a property of the building. Further, the wall has properties such as height, width, material, color, etc.
- Properties could have a degree of fulfillment/existence: Hartman refers to properties as existent or lacking (e.g. a bad chair is lacking a back, a good chair has a back, etc.). However, this does not account for the degree of fulfillment/existence of the property, or in other words the value of the property (e.g. is the back good or bad? what is the material of the back? is the material of the back good or bad?, etc.). Similarly (speaking of buildings), we need to address the following question: is the material of the wall good or bad? To answer this question, we need to define what makes the material of the wall good or bad. More precisely, we need to define what makes the material of the wall good or bad in terms of its material resource efficiency, noise level minimization, etc. This means that, in order to determine the value of an object, we need to define the value of the property (or properties) of that object. For example, in order to define the value of the 'wall,' we need to determine whether the 'material resource efficiency' of the 'material' is good or bad? This could be determined according to one or more indicators (in this example it could be the 'recycled content rate').
- The worth of a property in comparison to another: As mentioned above, Hartman established the principle that each property of the thing is worth as much as the other, if they are all on the same level of abstraction (the same level in the concept tree). This is arguable. For example, given that a chair has three properties (e.g. structure, back, seat), it can be argued that the seat is more important to the chair than the back (you can still sit on a chair without a back). Similarly, given that a wall has a set of properties (height, width, material,

color, etc.), it can be argued that the color is of less worth/importance than the material (if aesthetics is not that important to the value assessor).

- Valuation of buildings and building components: Buildings and building components (wall, floor, ceiling, window, door, etc.) are extrinsic objects that can be valuated systemically, extrinsically, and/or intrinsically (see Table-1 for examples). Fig. 1 shows a schematic diagram of the proposed process of axiology-based assessment/measurement of building project value. The valuation is performed by an assessor (an individual or an organization). The process of assessing building project values involves identifying the objects that add or hold value (i.e. the value bearers). From a systemic, extrinsic, and/or intrinsic perspective, the set of properties that are needed to characterize that object are defined. Based on the degree of fulfillment of these properties, the value of the object is assessed. Each building object is individually evaluated, and the corresponding individual values are aggregated in order to reach a global value. The following section includes are more detailed introduction to the axiology-based value analysis model.

Table-1: Examples of Value Dimensions

Valuation	Valuation Dimension
The house (or its design) complies with the code	Systemic valuation of an extrinsic thing *
The house is functional	Extrinsic valuation of an extrinsic thing *
The house is unique	Intrinsic valuation of an extrinsic thing*
* Here the 'thing' is the house (or its design)	

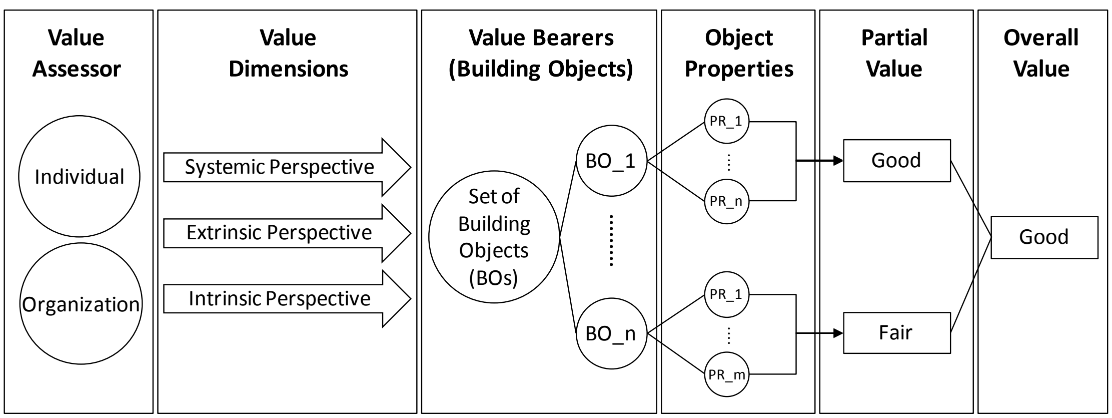

Figure 1: The proposed process of axiology-based assessment of building project value

3. PRELIMINARY AXIOLOGICAL MODEL FOR VALUE ANALYSIS OF BUILDING PROJECTS

The value analysis system presented in this paper consists of two layers (see Figure 2): a value layer and a building project layer. The purpose of the value layer is to define and measure the value of a building project or a building project component (i.e. a building object). The building project and the building project components (building objects) are defined in the building project layer.

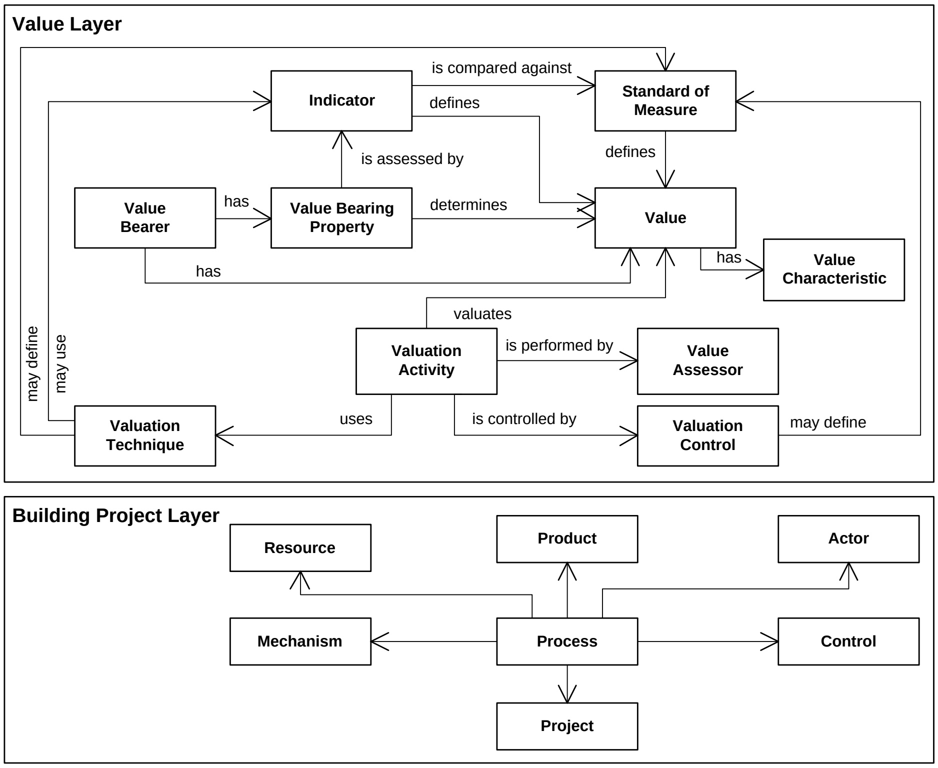

Figure 2: Overview of the layers in the proposed value analysis system

The value layer is built on an axiological model. The axiological model is structured into axiological concepts, inter-concept relations, and axiological axioms. An axiological concept (see Figure 3) is a *value bearer*, a *value*, a *value bearing property*, a *value assessor*, a *valuation activity*, a *valuation mechanism*, a *valuation control*, and a *value characteristic* (El-Gohary and Qari, 2010). A *valuation activity* is performed by a *value assessor* using a *valuation mechanism* to assess the *value* of a *value bearer* based on its *value bearing properties* and is controlled by a *valuation control*; and a *value* has a *value characteristic*. A *value bearer* is an object that has value, such as an actor, process, product, resource, or project. A *value* is a relative or absolute worth, merit, utility or importance (e.g. quality, safety, profit, comfort, etc.). A *value bearer* has one or more *value bearing properties* (e.g. 'material recycled content,' 'carbon emission level,' 'cost,' etc.) that directly or indirectly determine its *value*. A *value assessor* is an individual or organization (e.g. a 'designer') that assesses the *value* of the *value bearer*. A *valuation activity* is performed to valuate the value of a value bearer (e.g. an analysis, measurement, judgment, etc.). A *valuation mechanism* is a 'value analysis guide,' a 'value analysis technique,' an 'indicator,' or a 'standard of measure' that is used to valuate a value. Based on the chosen 'value analysis technique' (e.g. LEED), one or more indicators could be used. 'Indicators' are useful for monitoring and measuring a 'value' (whether it is an environmental, social, or economic value) by considering a manageable number of variable. On the other hand, a 'standard of measure' is the yardstick against which an indicator is measured to define if the value is good, fair, bad, etc. A *value control* is a regulatory, technical, contractual, or practical control that directs or constraints the *valuation activity* (e.g. environmental regulations, codes, standards, stakeholder requirements, etc.). A *value* has a *value characteristic*, which could be a *value property* or a *value modality*. A *value property* is a characteristic that describes a value. A *value modality* is a characteristic that describes a value and denotes its belonging to a particular category of values. Two categories of values (modalities) are defined in this papers: sustainability modality (environmental versus economic versus social values) and innateness modality (intrinsic versus extrinsic versus systemic). This paper focuses on the valuation of building objects (a 'building object' is a subclass of 'product'). Axiological axioms are a set of formal rules – defined using axiological logic – that establish the relative or absolute values of value bearers based on its value bearing properties. Axiological logic is a type of modal logic that deals with values, using notions such as good, bad, fair, etc.

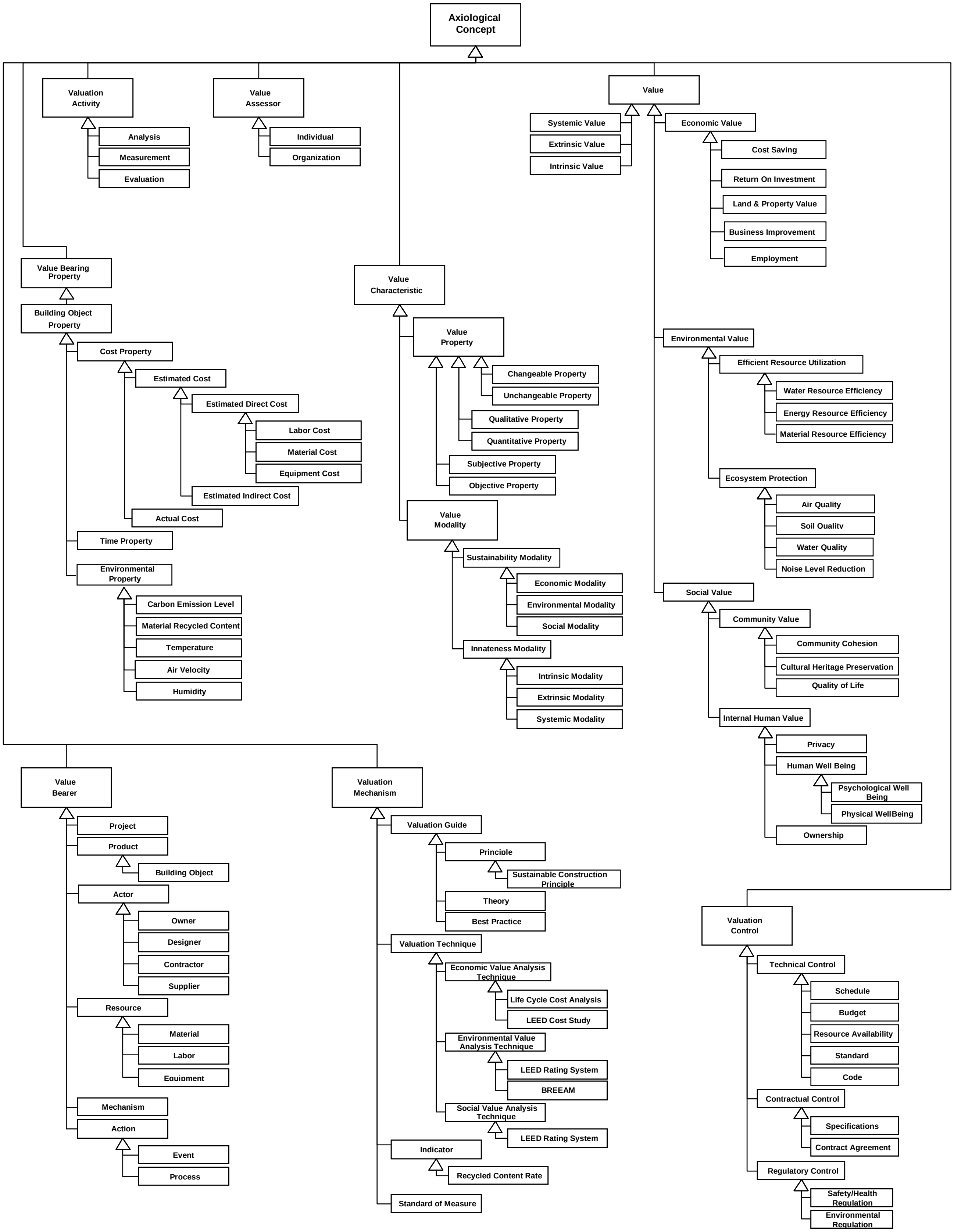

Figure 3: Preliminary axiological model for building projects

Figure 4 illustrates how the above-described model can be used to assess the 'material resource efficiency' of a 'wall.' According to the axiological model, a 'wall' is a type of 'building object' and is part of a 'building'; and a 'building object' is a type of 'value bearer.' On the other hand, 'material resource efficiency' is an 'environmental value' and an 'environmental value' is a type of 'value.' The 'wall' has one 'value bearing building object property' that determines its 'material resource efficiency:' 'material recycled content.' (For simplification of the example, only one property was used. In reality, several properties may be used to determine one value). The 'valuation activity' is performed by the 'designer' (a type of 'value assessor') to valuate the 'material resource efficiency' of the 'wall' based on the subject 'value bearing building object property' using the 'LEED rating system.' The 'LEED rating system' is a type of 'environmental valuation technique' and the 'environmental valuation technique' is a type of 'valuation technique' and a 'valuation technique' is a type of 'valuation mechanism.' Based on the 'LEED rating system' the 'recycled content rate' indicator is used, along with a 'standard of measure,' to define the 'material resource efficiency.' The 'standard of measure' is defined according to regulatory requirements, contractual requirements, owner requirements, etc. (types of 'valuation control'). The overall 'valuation activity' is also controlled by 'environmental regulations.' 'Environmental regulations' is a type of 'regulatory control' and a 'regulatory control' is a type of 'valuation control.'

In a similar manner, the rest of the environmental values (energy resource efficiency, noise level minimization, etc.) for the subject wall can be assessed. By aggregating all the sub-values, the total environmental value of the wall can be measured. Similarly, by aggregating the environmental, social, and economic values of the wall, the total value of the wall can be assessed. Then, by aggregating the values of all building objects, the total value a building can be determined. The aggregation methodology uses axiological logic. The methodology is outside the scope of this paper and will be presented in future work.

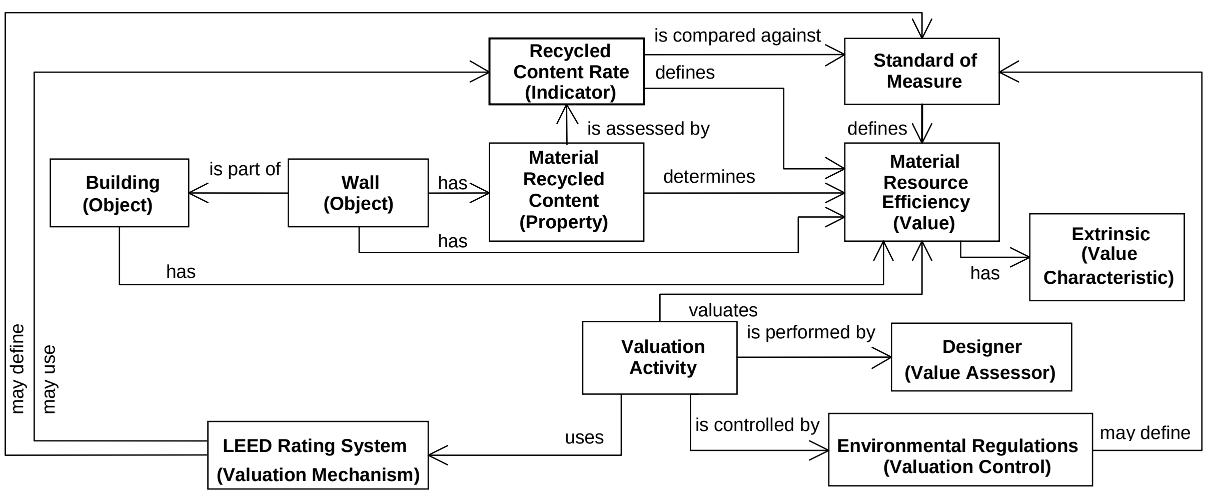

Figure 4: Example of assessing the 'material resource efficiency' of a 'wall' object

4. INTEGRATION OF THE AXIOLOGICAL MODEL AND THE IFC-BIM MODEL

A discussed above, building data or information (about building objects and building object properties) can be utilized for axiology-based building value analysis. This means that we need to acquire these building data or information and integrate it with the axiological model. Within this context, Building Information Modeling (BIM) is currently promising to facilitate the interoperability and integration of project information in the building construction industry (Eastman, et al., 2008; Azhar, et al., 2008). A Building Information Model (BIM) is intended to represents all the geometrical and non-geometrical characteristics of a building and their related life-cycle project information - it is intended to be a repository of information to use and maintain throughout the life-cycle of a building. In order to exchange project information between different applications or models, the current key efforts in the area of BIM are the Industry Foundation Classes (IFC). The main goal of the IFC is to specify a common language for technology to improve the communication, productivity, delivery time, cost, and quality throughout the entire project life cycle. Each specification (called a 'class') is used to describe a range of things that have common characteristics. These IFC-based objects aim to allow AEC/FM professionals to share a project model, while allowing each profession to define its own view of the objects contained within the model (IAI, 2003). The 'Shared Building Elements' part of the IFC specification contains entities that represent the basic components of a building, such as a wall, column, slab, door, etc. Each instance of these entities corresponds to an element of a building in a BIM. The resource layer of IFC contains categories of entities representing basic properties, such as geometry, material, quantity, time, and cost.

The framework for integrating the axiological model and the IFC-BIM model is described in Figure 5. The key is to link the 'building objects' and 'building object properties' in the axiological model with the corresponding entities in the IFC model, and then acquire the needed data. A 'building object' in the axiological model (e.g. a 'Door') is linked with a corresponding '*IfcBuildingElement*' (e.g. '*IfcDoor*'). The information required for defining the 'building object properties' in the axiological model can be acquired from several different IFC entities: common or customized IFC properties are linked with the 'building object properties' (in the axiological model). For example, with reference to Figure 4, in order to assess the 'material resource efficiency' of a 'wall' based on the axiological model, we need to link classes from the axiological model with classes from the IFC-BIM model. For this example, the 'Wall' (in the axiological model) is linked with the '*IfcWall*;' and the 'material recycled content' (in the axiological model) is acquired based on the '*IfcMaterial*' and '*IfcMaterialProperties*.'

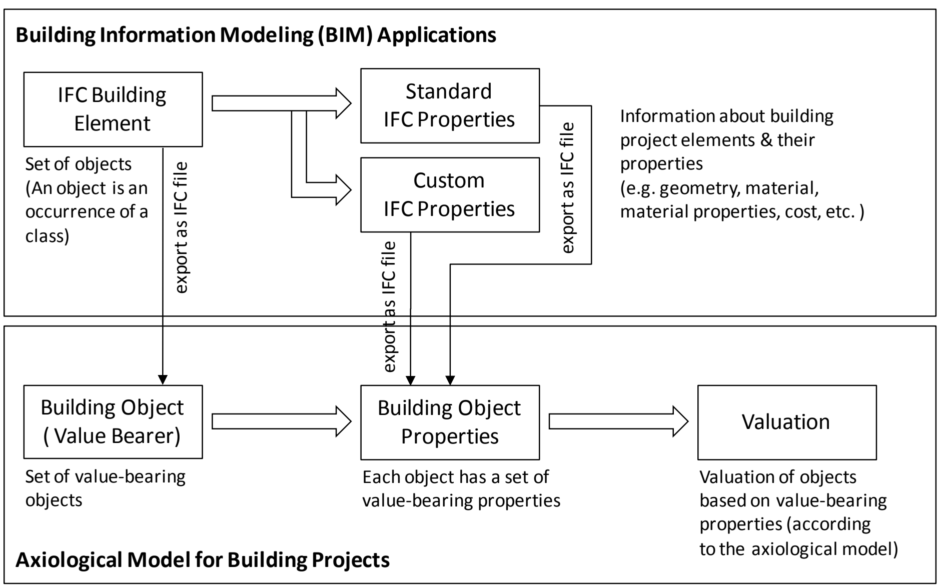

Figure 5: Framework for integrating the axiological model and the IFC-BIM model

5. SUMMARY AND CONCLUSION

In this paper, an axiology-based approach for value analysis of building projects is presented and discussed. The approach is intended to offer a holistic and formal theory-based means for building value assessment. The approach involves developing a formal axiology-based value model for building projects, and integrating the value model with the IFC-based building model. The initial axiological model for building projects is presented. The model supports the identification and measurement of multi-dimensional values of each building object (element) and aggregating these values to define the overall value of the whole building system. The formal representation of the model, along with the integration with BIM, will facilitate the automation of the value analysis process. The methodology for aggregating individual values of building objects to determine the overall value of the building system will be presented in future work. An axiology-based decision-support system for value analysis of building projects is under development. This model is the first axiological modeling effort in the construction domain. The use of this model can support the sustainability of building projects by considering economic, environmental, and social values during the overall project life-cycle.

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