Leadership in Sustainable Infrastructure

*Leadership en Infrastructures Durables*

Vancouver, Canada

May 31 – June 3, 2017/ *Mai 31 – Juin 3, 2017*

# EXPLORING THE SYNERGY BETWEEN BUILDING DESIGN AND HUMAN VALUES: BIM-BASED HUMAN VALUE ANALYSIS OF EDUCATIONAL BUILDINGS

Lu Zhang [1, 3], and Nora El-Gohary [2]

[1] School of Construction, Florida International University, USA

[2] Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign, USA

[3] luzhang@fiu.edu

## ABSTRACT

The fundamental goal of any building is to deliver value to its stakeholders. However, without a quantitative analysis of what human values (e.g., energy conservation, fire safety, cost saving) the building fulfills – and to what extent – and how that is aligned with the personal value systems of the stakeholders, the process of value delivery is uncertain. There is still a lack of quantitative understanding and analysis of the value of a building based on multidimensional human values. To address this gap, this paper presents a study on human value analysis of buildings for supporting value-adding and stakeholder-centered decision making in building design. The paper focuses on the analysis of an educational building to study the impacts of alternative design decisions on the value the building brings to different stakeholders. The analysis was conducted using a building information modeling (BIM)-integrated prototype system for automated human value analysis of buildings, which includes a stakeholder input capturing module, a building information extraction module, and a value analysis module. A set of stakeholders were invited to participate in the study. The stakeholders' systems of value priorities were first captured through the stakeholder input capturing module. The value-specific design information was then extracted from the BIM model of the building through the building information extraction module. Based on the stakeholders' systems of value priorities and the extracted design information, the value of the building was then quantified using the value analysis module. The results indicate that, in order to deliver high-value buildings to the stakeholders, decision makers should not only enhance the design to fulfill individual stakeholder values, but also take the stakeholders' systems of value priorities into account and seek to create a high level of synergy between the value created by the building and the value systems of the stakeholders.

Keywords: value analysis; human values; building design; building information modeling

## 1. INTRODUCTION

Building systems are constantly evolving, and are becoming more complex than ever before. Multiple institutions, organizations, and individual researchers have been calling for enhanced lifecycle environmental, social, and economic value of the built environment (e.g., Levitt 2007) Thus, more value-adding decision making during building planning and design is urgently needed. However, there is a lack of systematic method that explicitly quantifies or analyzes the value (Mills et al. 2006). Value "is a complex construct, with varied meaning" (Barima 2009); it is interpreted differently by different stakeholders (Thomson et al. 2003). The same building could offer different value to different stakeholders. The value (worth) of a building to an individual not only depends on what human values (e.g., safety, cost saving, energy conservation) that building can fulfill, but also relies on how important these values are to that individual. Therefore, the analysis of building value and how such value is impacted by the various planning and design decisions should be coupled with a representation of the human values of the stakeholders. Without a systematic analysis of the value of buildings from such a human-centered perspective, building decision making becomes limited in delivering high value to the stakeholders (Mukherjee and Muga 2009). There is, thus, a need to analyze the value of a building based on multidimensional human values to provide a quantitative foundation for value-adding and human-centered decision making during building planning and design.

Despite the evident need for human-centered and value-adding decision making, it is challenging to evaluate a building based on human values and to analyze how alternative planning and design decisions affect the value (worth) of the building. Existing value approaches (e.g., value engineering) lack the integration with human values or stakeholders' perspectives (Liu and Leung 2002). As a result, existing decision-making practices are limited in considering the human factors in value perception (Satty and Begicevic 2010). Different researchers and institutions have been calling for the need of engaging stakeholders in the analysis of value delivery to understand what the stakeholders truly value (Mills et al. 2006) and how important the values are to them. The content of such analysis must extend the investigation of pure function analysis to expose stakeholders' human values and their systems of value priorities. Such analysis is crucial for incorporating more human-centered thinking in value-based decision-making practices (Mukherjee and Muga 2009).

In order to support value-adding and human-centered decision making in building planning and design, Zhang and El-Gohary (2016a, 2016b) proposed a building infrastructure axiology (Build-Infra-Axio). The Build-Infra-Axio is a value-theoretic model that quantifies and analyzes the value (worth) of a building based on its properties (e.g., acoustic rating, recycled material, fire rating) and multidimensional stakeholder values (e.g., acoustic comfort, material conservation, fire safety). Based on the Build-Infra-Axio, Zhang and El-Gohary (2017) developed a building information modeling (BIM)-integrated value analysis system (BiVAS) that automatically quantify the value of a building using information extracted from an existing BIM model. The BIM-integrated system includes three modules: (1) a module for soliciting information about a stakeholder's personal value system; (2) a module for retrieving value-specific design information (i.e., relevant and sufficient information for value analysis including building objects and their properties) from a BIM model; and (3) a module for quantifying and aggregating the value of a building to a stakeholder based on the stakeholder's personal value system and the building properties. This system could support the value analysis process in an automated manner, which is the key to facilitate value-adding decision making in a more effective and efficient manner.

This paper presents a study on human-centered automated value analysis of educational buildings. The analysis is conducted using the BIM-integrated value analysis system. A set of experiments were conducted, using the proposed system, to analyze (1) the impact of alternative planning and design decisions on the degrees that an educational building fulfills different stakeholder values, and (2) the impact of the stakeholders' systems of value priorities on the values (worths) of different design alternatives.

## 2. POINTS OF DEPARTURE

Zhang and El-Gohary (2015a, 2016b, 2016, 2017) have conducted a series of research to support human-centered value analysis of buildings. Zhang and El-Gohary (2015a) discovered what different stakeholders value in the context of buildings. Fifty stakeholder values (e.g., energy conservation, cost saving, fire safety) were identified and classified. Zhang and El-Gohary (2015b, 2016) developed a building infrastructure axiology (Build-Infra-Axio), which includes (1) a mathematical value quantification model for quantifying the degree that a single building object (e.g., wall, door) fulfills one specific stakeholder value (e.g., energy conservation) based on its properties, and (2) a mathematical value aggregation model for aggregating the degrees that each of the building objects fulfills each of the stakeholder values to define the worth of the whole building system based on multiple stakeholder values. The models are theoretically grounded in axiology (theory of value) and integration theory.

As part of these models, an object-level value fulfillment degree function is used to define the value fulfillment degree of each stakeholder value by each building object. Such value fulfillment is quantified based on the goodness of the object properties and the significances of the properties in fulfilling this particular stakeholder value. The value fulfillment degree function is defined in Eq. 1:

[1] $VFD_{ja} = \sum_{i=1}^{n} PGD_{aij} \times PVS_{ij} + a \sum_{i=1}^{n} PVS_{ij} \times max\left[0, (PGD_{aij} - HPGL_{ij})\right]$

where $VFD_{ja}$= value fulfillment degree of stakeholder value *j* by building object *a*; *n* = total number of properties that contribute to fulfill stakeholder value *j*; $PGD_{aij}$= property goodness degree of property *i* of building object *a* in fulfilling stakeholder value *j*; $PVS_{ij}$= property value significance of property *i* in fulfilling stakeholder value *j*; $a$ = a coefficient for rewarding highly good properties; and $HPGL_{ij}$ = high property goodness line of property *i* in fulfilling stakeholder value *j*.

The different value fulfillment degrees of the building objects are then aggregated to define the value fulfillment degree of the whole building. The degree that a whole building system fulfills a specific stakeholder value is quantified based on how much its building objects – individually – fulfill this stakeholder value, how important these individual objects are in value fulfillment, how good or bad these objects physically integrate for value fulfillment, and how these objects match or mismatch in value fulfillment. The value fulfillment degree function of the whole building system is defined in Eq. 2.

[2] $VFD_{jk} = \sum_{\substack{a,b \in K \\ a \neq b}} \frac{(VFD_{jak} \times OVI_{jak} + VFD_{jbk} \times OVI_{jbk})(1+OIGD_{jabk})^{\beta}(1-OVMD_{jabk})^{\gamma}}{n-1}$

where $VFD_{jk}$= value fulfillment degree of building *k* in fulfilling stakeholder value *j*; $VFD_{jak}$= value fulfillment degree of building object *a* (of whole building *k*) in fulfilling stakeholder value *j*; $VFD_{jbk}$= value fulfillment degree of building object *b* (of whole building *k*) in fulfilling stakeholder value *j*; $OVI_{jak}$= object value importance of building object *a* (of whole building *k*) in fulfilling stakeholder value *j*; $OVI_{jbk}$= object value importance of building object *b* (of whole building *k*) in fulfilling stakeholder value *j*; $OIGD_{jabk}$= objet integration goodness degree between building objects *a* and *b* (of whole building *k)* in fulfilling stakeholder value *j*; $OVMD_{jabk}$ = object value mismatch degree between building objects *a* and *b* (of whole building *k*) in fulfilling stakeholder value *j*; *K*= the set of building objects that form building *k*; *n* = total number of building objects (of whole building *k*) that fulfill stakeholder value *j*; $\beta$ = a coefficient for controlling the degree of rewarding integration goodness, and $\gamma$ = a coefficient for controlling the degree of penalizing value mismatch.

The different value fulfillment degrees of the whole building system are further aggregated to define the worth of the whole building system. The worth of a building to a stakeholder depends on (1) how that building fulfills each of the individual stakeholder values (i.e., the value fulfillment degrees of the building for the different stakeholder values), (2) the stakeholder's personal system of value priorities (i.e., the importances of the different values to that stakeholder), which is represented through the concept stakeholder value importance (SVI), and (3) how synergistically the whole set of stakeholder values that are fulfilled by that building are collectively aligned with the stakeholder's personal system of value priorities. The worth function aims to capture the amount of worth of a building to a stakeholder taking both the fulfillment-importance alignment of the individual stakeholder values and the overall value system synergy into account. It is defined in Eq. 3.

[3] $W_{km} = \left(\sum_{j=1}^{n} VFD_{jk} \times SVI_{jkm}\right) \times \left(1 + \rho(VFD_{jk}, SVI_{jkm})\right)^{\delta}$

where $W_{km}$= the worth of building *k* to stakeholder *m*; *n* = total number of stakeholder values fulfilled by building *k*; $VFD_{jk}$= value fulfillment degree of stakeholder value *j* by building *k*; $SVI_{jkm}$= stakeholder value importance of stakeholder value *j* to stakeholder *m* for building *k*; $\rho\left(VFD_{jk}, SVI_{jkm}\right)$ = Spearman's ρ correlation coefficient of $VFD_{jk}$ and $SVI_{jkm}$; and $\delta$ = coefficient of value synergy between the VFDs and the SVIs of all stakeholder values fulfilled by building *k*.

Zhang and El-Gohary (2015a, 2016b, 2016, 2017) have provided contributions towards stakeholder value discovery and value analysis in the context of buildings. However, these research efforts did not focus on analyzing how alternative design decisions affect the value of buildings, such as how alternative design decisions affect the degree that a building fulfills different stakeholder values, or how the stakeholders' systems of value priorities affect the worth of a building to the stakeholders. There is still a lack of research that integrates human values with value analysis to support value-adding and human-centered decision making.

## 3. VALUE ANALYSIS EXPERIMENTAL DESIGN

An experiment was designed and conducted in the context of educational buildings, in order to answer the following research questions:

- How would particular design decisions (e.g., particular selection of materials) affect the value fulfillment degrees of different stakeholder values?
- How would the stakeholders' systems of value priorities (importance ratings of each of the stakeholder values) affect the worths of different design alternatives?

In the experiment, one-to-one stakeholder interviews were conducted to have the stakeholders use the BiVAS to analyze the value of a building based on their own systems of value priorities. The experiment was composed of three parts: (1) capturing the stakeholders' systems of value priorities (i.e., the importance ratings of the stakeholder values) through the BiVAS, (2) analyzing the value of the same set of design alternatives for the same set of stakeholders using the BiVAS, based on the captured systems of value priorities, and (3) analyzing the value analysis results generated by the BiVAS.

The BIM model of the Electrical and Computer Engineering (ECE) building at the University of Illinois at Urbana-Champaign was used for the experiment. The 230,000 square feet ECE building was designed by SmithGroup. The building provides 45 instructional and research labs, 48 private faculty offices, 280 graduate student workstations, and a variety of areas for student study and coloration. The building received a LEED Platinum certification (SmithGroupJJR 2016).

For simplicity and efficiency of the experiments, six major systems (or components) of the building were identified and studied in the experiments: exterior wall system, roofing system, flooring system, windows, doors, and stairs (including railings). Two additional design alternatives (with different elements and properties) – in addition to the original design – were developed in consultation with three architectural designers. The information about the original design as well as the two alternative designs are partially summarized in Table 1. Accordingly, seven relevant stakeholder values were considered in the experiment: energy conservation, material conservation, indoor air quality improvement, acoustic comfort, fire safety, and cost saving.

## 4. VALUE ANALYSIS EXPERIMENTAL IMPLEMENTATION

The target participants for the experiment are the real stakeholders of the ECE building, including students, student groups, faculty, as well as responsible stakeholders such as the designer, contractor, and facility manager. A total of 28 potential participants were identified and contacted via email.

Each stakeholder interview was conducted in four parts: (1) a short presentation by the interviewer (first author) to introduce the research purpose, (2) a short demo to explain the functions of the proposed system, (3) a walkthrough of the design details and the properties of the three design alternatives, and (4) an opportunity for the participants to use the BiVAS to analyze the value (worth) of the three design alternatives based on their own value systems.

## 5. VALUE ANALYSIS EXPERIMENTAL RESULTS AND ANALYSIS

### 5.1 Experimental Results

A total of 11 stakeholders participated in the interviews, representing a 39.0% response rate. This is slightly higher than "the norm of 20-30% with most questionnaire surveys in the construction industry" (Akintoye 2000). The system-based analysis was conducted using the BiVAS. The system captures the stakeholders' importance ratings of the set of stakeholder values, extracts the value-specific design information of each of the design alternatives from the BIM models, and then analyzes the value (worth) of each of the design alternatives based on the Build-Infra-Axio models.

Finally, the three alternatives were ranked based on their worths, in descending order. The partial results of the system-based analysis of the three alternatives of each experiment, are presented in Tables 2 and 3.

Table 1 Partial Design Details of the Three Alternatives

| A[a] | Component | Exterior wall A | Roof | Floor (ground level) | Window | Door (Main Entrance) |
|---|---|---|---|---|---|---|
| Alternative I | Name | Concrete block wall | Metal roof | Concrete floor | Fixed window | Glass entry door |
| | Structure/framing | 12" x 8" x 16" Concrete block | Steel bar joist layer | 6" Concrete slab on grade | Metal bronze frame | Metal aluminum frame |
| | Interior sheathing | 5/8" Gypsum board | 1/2" Protection board | 5/8" Type X gypsum board | N/A | N/A |
| | Insulation | 4" Exterior insulation and finish system (EIFS) | 2 Layers of 2" Polyisocyanurate rigid insulation | 3" EPS rigid insulation | N/A | N/A |
| | Exterior sheathing | N/A | 1/2" Protection board | 3/4" Plywood sheathing | N/A | N/A |
| | Thermal/air layer | 1-5/8" Air infiltration barrier | N/A | N/A | N/A | N/A |
| | Membrane layer II (vapor retarder) | Included in EIFS | 1/4" Roof - EPDM membrane | 0.002" Polyethylene sheet | N/A | N/A |
| | Window glass pane/ Door panel | N/A | N/A | N/A | Double glazed, low-e glass, 1/2" air space | Fiberglass and aluminum, heavy duty |
| Alternative II | Name | Concrete block wall | Metal roof | Concrete floor | Operable window | Curtain wall double glass entry door |
| | Structure/framing | 12" x 8" x 16" Concrete block | Steel bar joist layer | 6" Cast in place concrete | Metal aluminum frame | Metal Aluminum frame |
| | Interior sheathing | 5/8" Type X gypsum wall board | 5/8" Type X gypsum board | 5/8" Type X gypsum board | N/A | N/A |
| | Insulation | 4" Exterior insulation and finish system (EIFS) | 3" EPS rigid insulation | 3" EPS rigid insulation | N/A | N/A |
| | Exterior sheathing | N/A | Steel roof panel | 3/4" Plywood sheathing | N/A | N/A |
| | Thermal/air layer | 1-5/8" Air infiltration barrier | N/A | N/A | N/A | N/A |
| | Membrane layer II (vapor retarder) | N/A | N/A | 0.002" Polyethylene sheet | N/A | N/A |
| | Window glass pane/ Door panel | N/A | N/A | N/A | Single hung, enameled, standard glazed with insulating glass | Fiberglass and aluminum, heavy duty |
| Alternative III | Name | Insulating concrete form (ICF) wall | Metal roof | ICF floor | Fixed window | Glass entry door |
| | Structure/framing | 8" Reinforcing concrete (included in ICF) | Steel bar joist layer | 6" Reinforcing concrete (included in ICF) | Metal bronze frame | Metal Aluminum frame |
| | Interior sheathing | 1/2" Gypsum board | 1/2" Protection board | 1/2" Gypsum board | N/A | N/A |
| | Insulation | 2 Faces of 3-3/8" EPS foam (included in ICF) | 2 Layers of 2" Polyisocyanurate rigid insulation | 11-3/8" EPS foam (included in ICF) | N/A | N/A |
| | Exterior sheathing | N/A | 1/2" Protection board | 5/8" Plywood sheathing | N/A | N/A |
| | Membrane layer (vapor barrier) | Spunbonded polyolefin (SBPO) air and water barrier | 1/4" Roof - EPDM membrane | N/A | N/A | N/A |
| | Window glass pane/Door panel | N/A | N/A | N/A | Triple glazed, low-e glass, 1/2" air space | Fiberglass and aluminum, heavy duty, sectional, 12' x 12' high |

Table 2. Value Fulfillment Degrees of Stakeholder Values

| Stakeholder value | Value Fulfillment Degrees of Stakeholder Values | | |
|---|---|---|---|
| | Alt. I | Alt. II | Alt. III |
| Energy conservation | 0.852 | 0.532 | 0.983 |
| Daylight and views improvement | 0.905 | 0.644 | 0.818 |
| Material conservation | 0.709 | 0.700 | 0.374 |
| Indoor air quality improvement | 0.804 | 0.686 | 0.793 |
| Acoustic comfort | 0.578 | 0.671 | 0.468 |
| Fire safety | 0.705 | 0.756 | 0.560 |
| Cost saving | 0.580 | 0.694 | 0.640 |

Table 3. Worths of Alternatives to the Stakeholders

| Respondent | Worths of Alternatives | | |
|---|---|---|---|
| | Alt. I | Alt. II | Alt. III |
| 1 | 0.850 | 0.415 | 0.819 |
| 2 | 0.827 | 0.676 | 0.748 |
| 3 | 0.720 | 0.671 | 0.610 |
| 4 | 0.469 | 0.860 | 0.586 |
| 5 | 0.654 | 0.240 | 0.642 |
| 6 | 0.697 | 0.644 | 0.604 |
| 7 | 0.837 | 0.465 | 0.792 |
| 8 | 0.923 | 0.514 | 0.852 |
| 9 | 0.806 | 0.415 | 0.731 |
| 10 | 0.639 | 0.636 | 0.561 |
| 11 | 0.696 | 0.670 | 0.708 |

### 5.2 Experimental Analysis and Discussion

Analysis of impact of alternative design decisions on the value fulfillment degrees of stakeholder values

As per Table 2, among the three design alternatives, Alternative I has the highest value fulfillment degrees in daylight and views improvement, material conservation, and indoor air quality improvement. Alternative I uses curtain walls as part of its envelope systems; the curtain walls feature relatively high visible transmittance glass panes, which could offer the maximum amount of daylight to support occupant activities in the building. This leads to the highest value fulfillment degree in daylight and views improvement (0.905) among the three alternatives. This reduces the need to turn on lights, and allows in warmth from the sun in the winter, thus facilitating energy efficiency simultaneously. Besides the selection of glazing materials, the louvered metal canopy above the hallway also contributes to daylight and views improvement by blocking hot sunlight in the summer and allowing it inside during the winter (ECE Illinois 2016). Alternative I of the ECE building also offers the highest value fulfillment degree of material conservation (0.709) among the three design alternatives. It features the use of a high percentage of regional and recycled materials. Material selection plays a key role in sustainable building planning and design. The use of material from regional/local resources not only supports the local economy but also reduces transportation impact on the environment. By selecting products containing recycled content, the consumption of raw materials could be reduced and the amount of waste for landfills is also reduced (USGBC 2009). In this specific case, the design uses regional materials such as granite from Minnesota, glass from Wisconsin, and bricks and steel from Indiana. It also uses recycled material, such as counter tops made from resin and recycled wood fiber and metal lab cabinets made from recycled materials. Alternative I also features steel reinforcement, structural steel, and steel decking with a high percentage of recycled material (ECE Illinois 2016).

Alternative II, on the other hand, has relatively high value fulfillment degrees in acoustic comfort (0.671) and fire safety (0.756). This is mostly because this design replaces the original curtain walls with concrete block walls, which features utmost protection against fire (IMI 2017) and a high level of sound resistance capability (NCMA 2012).

Alternative III offers the highest value fulfillment degree (0.983) in energy conservation among all three alternatives. This is because of the selection of insulating concrete form (ICF) to replace part of the original concrete block wall systems. IFC is a system of formwork for reinforced concrete made with a rigid thermal insulation that serves as a permanent interior and exterior substrate for walls, floors, or roofs (ICFA 2017). This offers continuous high thermal performance throughout the envelope systems, airtight construction, and thermal mass mitigation (ICFA 2017), which collectively contribute to the best fulfillment of energy conservation value.

Analysis of impact of the stakeholders' systems of value priorities on worths

The value (worth) of a design alternative to a stakeholder depends on the stakeholder's personal system of value priorities (i.e., the importances of different stakeholder values to a specific stakeholder) and how this design alternative fulfills these stakeholder values. It also depends on how synergistically the whole set of stakeholder values fulfilled by that design alternative are collectively aligned with the stakeholder's personal system of value priorities. Accordingly, as per Table 3, using the BiVAS, the worths of the alternatives are different to the different stakeholders.

First, different design alternatives offer different worths to the same stakeholder based on his/her personal system of value priorities. In general, Alternative I provides the highest worth to the respondents who attached high importance (at least "important") to daylight and views improvement and indoor air quality improvement. Alternative II provides the highest worth to the respondents who attached high importance to acoustic comfort, fire safety, and cost saving. Alternative III provides the highest worth to the respondents who attached high importance to energy conservation. For example, among the three design alternatives, Alternative I offers the highest worth (0.904) to Respondent#5, while Alternative II offers the lowest worth (0.558) to this same respondent, who rated daylight and views improvement as "extremely important", indoor air quality and material conservation as "very important", fire safety, energy conservation, and material conservation as "important", and cost saving as "slightly important". This is caused by two main reasons. First, Alternative I outperforms the other two alternatives in several stakeholder values. Among the three alternatives, Alternative I best fulfills daylight and views improvement (VFD=0.905), indoor air quality (VFD=0.804), and material conservation (VFD=0.709). It also has a very high value fulfillment degree (0.852) in energy conservation. Second and most importantly, the whole set of stakeholder values fulfilled by Alternative I were collectively aligned with the respondent's personal system of value priorities, which means that there is a high level of synergy between the two sets of stakeholder values – the set that the respondent values the most (e.g., daylight and views improvement, indoor air quality improvement, and material conservation) and the set that is actually fulfilled by Alternative I. On the other hand, although Alternative II outperforms the other two alternatives in acoustic comfort (VFD =0.671), fire safety (VFD = 0.756), and cost saving (VFD =0.694), the level of overall synergy between the respondent's value systems and the design's value fulfillment is relatively low. Therefore, in this specific case, Alternative I offers the highest worth to the respondent because it best fulfills certain stakeholder values and it achieves a high level of synergy with the respondent's value system.

Second, the same design alternative offers different worths to the different stakeholders based on their personal value systems. In general, Alternative III offers the highest worth to the respondents who attached high importance to energy conservation, but it offers the lowest worth to the respondents who attached high importance to material conservation, fire safety, and acoustic comfort. For example, among the three alternatives, Alternative III has the highest worth (0.708) to Respondent#11, who rated energy conservation and cost saving as "extremely important", material conservation, indoor air quality as "important", but acoustic comfort and fire safety as "slightly important". On the other hand, this same Alternative II offers the lowest worth (0.610) to Respondent #3, who rated acoustic comfort, fire safety, and daylight and views improvement as "extremely important". Compared to the other two design alternatives, Alternative III best fulfills energy conservation (VFD =0.983). But it also has the lowest value fulfillment degrees for material conservation (0.374), acoustic comfort (0.468), and fire safety (0.560). Thus, the whole set of stakeholder values fulfilled by Alternative III is collectively aligned with Respondent#11's personal value system, while it misaligned with Respondent#3's personal value system. In other words, Alternative III achieves a much higher level of synergy with the personal value system of Respondent#11 than that of Respondent#3. Therefore, the worth of the same Alternative III is much higher to Respondent#11 than to Respondent#3.

Based on the analysis of the results from the experiments, the stakeholders' systems of value priorities have significant impacts on the worths of the design alternatives to the different stakeholders – they can serve as key predictive and explanatory factors of stakeholders' preferences and selections. In order to provide the stakeholders with the best design alternative, decision makers should not only enhance the design's ability in fulfilling individual stakeholder values, but also account for the stakeholders' systems of value priorities, and strive to create a high level of synergy between the design's value fulfillment and stakeholders' value systems.

## 6. CONCLUSIONS AND FUTURE RESEARCH

This paper presented a study on value analysis of an educational building to facilitate value-adding and human-centered decision making in building planning and design. The value analysis was conducted, in an automated manner, using a BIM-integrated value analysis system (BiVAS). An experiment was designed and implemented, using the BiVAS, to analyze the impact of alternative planning and design decisions on the value of the educational building to the stakeholders. The results show that stakeholders' systems of value priorities strongly affect the worth of a building to the stakeholders. The same design could offer different worths to different stakeholders. Thus, it is important that decision makers not only enhance a design's ability in fulfilling individual stakeholder values, but also take the stakeholders' systems of value priorities into account and seek to create a high level of synergy between the design's value fulfillment and the stakeholders' value systems. In their future research, the authors will conduct further automated value analysis studies towards wider and deeper understanding of value delivery in the construction domain, such as what values are competing and what tradeoffs could be involved in design alternative selection. The analyses will be conducted in the context of different types and scales of buildings and civil infrastructure systems (highway, bridges).

## 7. ACKNOWLEDGEMENTS

The authors would like to thank the National Science Foundation (NSF). This paper is based upon work supported by NSF under Grant No. 1254679. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of NSF.

## 8. REFERENCES

Akintoye, A. 2000. Analysis of factors influencing project cost estimating practice. *Construction Management and Economics,* 18: 77–89.

Barima, O. 2009. Examination of the best, analogous, competing terms to describe value in construction projects. *International Journal of Project Management,* 28(3): 195–200.

Electrical and Computing Engineering Illinois (ECE Illinois). 2016. Energy efficiency features of the ECE building. < https://www.ece.illinois.edu/about/buildings/energy-efficiency.asp> (Jun 21, 2016).

Insulated Concrete Forms Alliance (ICFA). 2017. Building with ICFs. <http://www.forms.org/index.cfm/buildingicf> (Feb 15, 2017)

International Masonry Institute (IMI). 2017. Fire safety with masonry. <http://www.imiweb.org/imi_toolkit/pdf/FireSafetyMasonry.pdf> (Feb 15, 2017).

Levitt, R. 2007. CEM research for the next 50 years: Maximizing economic, environmental, and societal value of the built environment. *J. Constr. Eng. and Manage.*, 133(9): 619-628.

Liu, A.M.M., and Leung, M. 2002. Developing a soft value management model. *International Journal of Project Management*, 20(5): 341-349.

Mills, G.R., Austin, S.A., and Thomson, D.S.2006.Values and value – two perspectives on understanding stakeholders. Proc., the *Joint Intl. Conf. Construction Culture, Innovation, and Management*, the British University in Dubai, Dubai, UAE, 267-278.

Mukherjee, A., and Muga, H. 2009. A decision-making framework to assess stakeholder value in adoption of sustainable practices in construction. *Proc., 2009 Construction Research Congress*, ASCE, Reston, VA, 548-557.

National Concrete Masonry Association (NCMA). 2012. Sound transmission class ratings for concrete masonry walls. *Report TEK 13-1C,* Herndon, VA.

Satty, T.L. and Begicevic, N. 2010. The scope of human values and human activities in decision making. *Applied Soft Computing*, 10(4): 963-974.

Thomson, D., Austin, S., Devine-Wright, H. and Mills, G.R. 2003. Managing value and quality in design. *Building Research & Information*, 31(5): 334–45.
Zhang, L., and El-Gohary, N. 2015a. Discovering stakeholder values for axiology-based value analysis of building projects. *Journal of Construction Engineering and Management*, 10.1061/(ASCE)CO.1943-7862.0001004, 04015095
Zhang, L. and El-Gohary, N.M. 2015b. Axiology-based value quantification modeling for buildings. *Proceedings of the Canadian Society for Civil Engineering International Construction Specialty Conference (ICSC'15)*, University of British Columbia, Vancouver, BC, Canada.
Zhang, L., and El-Gohary, N. 2016. Human-centered Value Analysis: Building Value Aggregation based on Human Values and Building System Integration. *Journal of Construction Engineering and Management*, *In press*.
Zhang, L, and El-Gohary, N. 2017. BIM-integrated system for automated value analysis of buildings, *Proc., International workshop on Computing in Civil Engineering,* Seattle, WA.