RESEARCH

UNDERSTANDING THE PERCEIVED VALUE OF USING BIM FOR ENERGY SIMULATION

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ABSTRACT

Building Information Modeling (BIM) and Energy Simulation have both become increasingly important tools in the building sector. The potential exists to achieve a synergistic relationship between BIM and energy simulation software programs by leveraging information stored within BIM models to inform energy models to save time and improve a design's performance. This study seeks to understand the perceptions of green design stakeholders with regard to the value of BIM-based energy simulation as well as associated barriers and benefits. To do so, an e-survey was used to collect data. Data analysis consisted of descriptive statistics, Cronbach's Alpha coefficients, Spearman correlations, and Mann-Whitney U tests. Results suggest that little to no correlation exists between green design stakeholders' perceptions regarding the value of using information from BIMs to inform energy simulation, and their engagement level with BIM and/or energy simulation. While this study has been limited by its sample size and location of participants, the results help identify different user groups' perceptions and receptiveness to using BIM-based energy simulation tools, which are advancing and transforming the AEC industry. Studies, such as this, emphasize the need for further research on understanding the modeling processes related to energy simulation and BIM models.

KEYWORDS

BIM, energy modeling, building performance, design stakeholder, perceptions

1. INTRODUCTION

An increased awareness of climate change, increasingly stringent building codes, and rising energy costs are leading to a surge in global demand for better performing buildings, which has invited designers to pay more attention to building performance. Applying sustainable design principles can improve the overall performance of a building. However, difficulty exists in knowing the exact implications of design changes on overall building performance or in identifying interactive effects of such changes on individual building systems. In order to model

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potential impacts of design changes on building performance, designers often rely on energy simulations. Building Information Modeling (BIM) is a process that utilizes 3-D, parametric modeling software capable of storing project information that can be updated and extracted by various users throughout a building's life cycle. BIMs serve as repositories for storing and updating data that can be extracted and analyzed, and therefore, can be used to effectively inform the decision-making process during design (Azhar et al. 2009). As information repositories, BIMs provide a significant opportunity to leverage such information and inform energy simulations.

Architectural, Engineering, and Construction (AEC) industries are quickly adopting BIM as project management and design tools. A report from McGraw-Hill (2012) indicates BIM adoption increased from 28% in 2007 to 71% in 2012. Multiple studies have identified the benefits, trends, risks, challenges and perceptions of BIM related to such adoption (Azhar 2011, Bryde et al. 2013, McGraw-Hill 2012). Likewise, green design stakeholders are increasingly using energy simulation tools to inform or validate the decision-making process and to validate previous design decisions on projects where building performance is of high importance. Sparse literature exists that identifies green design stakeholders' perceptions on using BIM to aid in generating energy models and managing their simulations. In addition, less literature exists that identifies the main benefits and barriers perceived by green design stakeholders regarding using BIM models, which provide geometric relationships and material properties, to create energy simulations.

The purpose of this research is to identify the main perceived barriers and benefits associated with using BIM models for energy simulations. In addition, this study seeks to determine green design stakeholders' overall perceptions of the value associated with using BIM for energy simulations and to investigate how BIM and energy simulation engagement levels may impact their perceptions of value. The results presented help readers understand how to better implement BIM-based energy simulation while mitigating barriers and optimizing benefits. Additionally, examining discrepancies between user groups can lead to the identification and improvement of shortfalls in current BIM-based energy simulation processes. Finally, understanding how perceptions and engagement levels differ among different software user groups may help in developing strategies for implementing BIM-based energy simulation tailored to specific groups.

2. POINT OF DEPARTURE

Building Information Modeling (BIM) is a process that utilizes a 3-D, parametric design software that is capable of storing project information that can be updated and extracted by various users. BIM is capable of demonstrating the entire life cycle of a building virtually. Building Information Models (BIMs) are the virtual representations of a project that result from the BIM process, which can act as a communication platform between project stakeholders (Mowata and Carter 2013). BIMs are capable of representing the geometry, spatial relationships, geographic information, quantities and properties of building elements, and can be used to create cost estimates, material inventories, and project schedules (Azhar 2011). Unlike drafting tools such as AutoCAD, BIM allows for drawings to be completed more efficiently since it utilizes parametric change technology and can have robust information embedded within the model (Azhar et al. 2009). Parametric change technology maintains model consistency by allowing users to create a single model, that when updated, automatically reflects the changes made in all applicable model views. BIM also improves documentation reliability by providing a platform for multiple stakeholders to access and update information. In addition, fixing a problem in a computer model costs only a fraction of what it would cost to fix the mistake in the field (Smith and Tardif 2012).

BIM adoption rates among the Architectural, Engineering, and Construction (AEC) industry more than tripled between 2007 and 2012 because of the potential to increase productivity during a project's life cycle (McGraw-Hill 2012). For instance, owners can use BIM to recognize project needs, design teams can analyze several project scopes, general contractors can enhance coordination with vendors and suppliers, and facility managers can analyze the performance of the facility during the operation and decommissioning phases (Bryde et al. 2013). Additionally, indirect benefits, such as increased safety, enhanced quality, reduced schedules, cost savings, lower labor costs, and waste reduction may be realized from BIM implementation (Russell et al. 2014).

In general, the AEC industry holds a very positive perception of integrating BIM into workflows and those that adopt BIM perceive it to have a very positive impact on their company (McGraw-Hill 2008). Firms that track their Return on Investment (ROI) when using BIM on projects, showed initial ROIs of 300 to 500%. Also, such firms indicated higher value for using BIM on projects than those who did not track their ROI (McGraw-Hill 2008). In addition, as users gain experience with BIM, their view of its impact improves significantly (McGraw-Hill 2008).

Energy Simulation refers to the process of predicting a building's energy performance through software analysis, while an *energy model* refers to a computerized representation of a building and its properties that are used to perform energy simulation calculations (ASHRAE 2005). Building energy simulation programs are capable of evaluating energy impacts of multiple designs across dynamic interrelated systems in a rapid manner, which make them a valuable decision-making tool for design and construction professionals who seek high levels of building performance (Azhar et al. 2012). Iterative building performance analysis during the design process leads to more comprehensive feedback on the performance implications of design variations, which can lead to more energy efficient designs. Early design and preconstruction stages of a project are the critical phases for making design decisions on that impact energy performance (Azhar et al. 2012). Similar thinking is also emphasized by Attia and De Herde (2011) who argue that 20% of the design decisions taken earlier influence 80% of all subsequently design decision.

Despite the fact energy simulation software has become increasingly user-friendly and time-efficient to use, these software programs still require considerable time and expertise to complete with high levels of accuracy. A large number of parameters needed to run an energy simulation for a whole building and decision uncertainty early in the design process can yield a vast, under-determined parameter space (Raftery et al. 2011). Assumptions are necessary for under-determined parameter space. Inaccurate assumptions can lead to inaccuracies in building performance simulations, which ultimately leads to unreliable energy simulation results to base decisions on (Hong, Kim & Kwak 2011). In addition, buildings are often designed by multiple stakeholders who are in charge of designing distinct subsystems. Ineffective communication channels among stakeholders can result in incomplete information or delay in the transfer of information needed to run an energy simulation.

Energy modeling tends to be an involved and error-prone process, as it requires identifying and entering numerous inputs (Tang et al. 2010). However, leveraging geometries and information embedded in BIM models can greatly hasten and simplify the energy simulation input process (Kim et al. 2013). Since BIM programs give users the ability to store and update data about a building that can be periodically extracted and analyzed throughout the design process, an ideal opportunity exists to leverage this information to inform energy models and to ultimately improve the decision-making process (Azhar et al. 2009). The use of BIM-based energy simulation tools can simplify the burdensome, arduous process of running simulations (Azhar & Brown 2009) and can help users avoid the time-consuming, error-prone process of re-entering information pertaining to building components, geometry, etc. (Stumpf et al. 2009). BIM software used in conjunction with energy simulation software allow for building performance analysis of a structure to be performed more frequently. This iterative analysis of a project throughout the design phase ensures that performance criteria are maximized (Azhar et al. 2011). Since BIM-based energy simulation allows users to rapidly predict the performance of different designs, it can help designers choose a building design that maximizes functionality, cost and performance (Schade et al. 2011). For example, a study by Shoubi et al. (2015) demonstrated that by modeling, then running simulations on, different building configurations on a Malaysian based bungalow, they were able to achieve significant energy savings. BIM can reduce costs associated with traditional energy analysis by making information needed for the energy analysis process routinely available as a byproduct of the standard design process (Azhar et al. 2009). In addition, existing information databases can help inform assumptions about energy simulation in order to make them more accurately represent an actual building's operation and potentially improve the accuracy of a BIM (GSA 2012).

A number of barriers currently prevent the universal adoption of BIM-based energy simulation in the AEC industry. According to Azhar et al. (2010, p. 221) risks and challenges include: "lack of interoperability between various BIM-based applications, the relative slowness of the mechanical design community in adopting BIM, and lack of BIM-based analysis applications certified by the California Energy Commission." Additionally, project contract types and lack of proficiency with BIM and/or energy simulation tools act as challenges to levering information from BIMs to inform energy simulations to its fullest extent. Information that is needed to compile a complete BIM model is often fragmented, being created by various stakeholders throughout the lifecycle of a building (Mowata and Carter 2013). However, the integration of this information is essential in producing accurate energy simulation results. Although BIM-based energy simulation is far from perfect in predicting a building's energy usage, its use is growing in the AEC industries. Despite this growth, many construction companies still do not perceive an immediate need to use BIM for environmental/ sustainability analysis, however, they believe that it will become increasingly important in the near and far future (Ku and Taiebat 2011).

3. RESEARCH APPROACH

3.1 Survey Instrument

An e-survey was developed based on past studies to determine respondents' perceptions regarding leveraging BIM for energy simulation while observing demographic data about respondents. This survey allowed researchers to identify the factors that impact how green design stakeholders' engagement levels with BIM and/or energy simulation impacts their overall perceptions of leveraging BIM for energy simulation. An extensive literature review and interviews with design and construction professionals helped guide the development of the survey. During the development of the survey, open-ended feedback was provided from industry professionals and academics during two rounds of pilot testing.

The e-survey, consisting of four sections, includes: *Demographics*, *BIM Aptitude*, *Energy Simulation Aptitude*, and *How BIM and Energy Simulation Work Together*. The *Demographics* section gauges firm type, position title, company size, company zip code, and the breakdown of work type for each respondent. Demographic data is essential to provide meaningful context for survey results due to the high degree of variability across companies and professional practice throughout the AEC industry. Size ranges for this question were used directly from McGraw-Hill (2012), which distinguishes company sizes by annual revenue and firm type. Table 1 shows the categorization of firm sizes by firm type (construction related or design related) and net revenue ranges that were used in the survey instrument.

The BIM Aptitude and Energy Simulation Aptitude sections in the survey were included to better understand which distinct software products respondents used and to measure respondents' engagement levels. An index was adapted from a McGraw-Hill (2012) study to measure respondent engagement with BIM and energy simulation. This study was selected as a baseline since trade research often has a compelling impact on perceptions and is widely read, especially as it relates to technology application in the AEC industry. The engagement index is out of 27 points, where 27 indicates very high engagement scores, 19–26 indicates high engagement scores, 11–18 indicates a medium engagement score and 3–10 indicates a low engagement score. This engagement index is comprised of three categories: user experience, user expertise and firm implementation levels. These three categories are all self-reported by respondents. Experience measures the number of years a respondent has been using BIM. Expertise indicates the level each respondent selected as best representing his or her personal skills with BIM and energy simulation respectively. Implementation measures the percentage of projects being done in BIM and by the respondents' firm. For example, if one respondent indicated that he or she had 3 years of experience with BIM (3 points), had an advanced level of expertise with BIM (6 points), and was very heavy on implementation (8 points), therefore this respondent had an overall BIM engagement score of 17. Tables 2 and 3 show the breakdown of the engagement index point structure as well as firm classification respondent classification level.

TABLE 1. Firm sizes by firm type and net revenue.

	Firm Type	
Firm Size	**Construction Related (Construction Managers, General Contractors)**	**Design Related (Architects, Engineers, Energy Modelers, Energy Consultant, Owner & Other)**
Small firms	Less than $25 million	Less than $500,000
Small to medium firms	$25 million to less than $100 million	$500,000 to less than $5 million
Medium to large firms	$100 million to less than $500 million	$5 million to less than $10 million
Large firms	$500 million or more	$10 million or more

TABLE 2. BIM and Energy Simulation Engagement index point structure (Adapted from McGraw-Hill 2012).

Experience		Expertise		Implementation	
1 year	1 point	Beginner	1 point	Light (<15%)	1 point
2 years	2 points	Moderate	3 points	Moderate (15%–30%)	3 points
3 years	3 points	Advanced	6 points	Heavy (31%–60%)	5 points
4 years	4 points	Expert	10 points	Very heavy (Over 60%)	8 points
5 years	5 points				
> 5 years	9 points				

In addition, the *BIM Aptitude* and the *Energy Simulation Aptitude* sections determine which software products are used by each respondent's firm. BIM and energy simulation software programs were identified through an exhaustive literature review and through web searches. The *Energy Simulation Aptitude* section goes a step further to gauge respondents' perceptions of the accuracy of their energy simulation results at predicting actual building operation usage.

The last section, *How BIM and Energy Simulation Work Together*, determines if respondents use BIM models to inform their energy simulation(s) and if so measures respondents' overall perceptions of using BIMs to inform energy simulations using a seven-point Likert scale. Additionally, this survey section investigates respondents' overall perceptions of the benefits and barriers associated with leveraging BIM for energy simulation by asking them to what degree they agree/disagree with a series of statements that pertain to the benefits and barriers associated with using BIM for energy simulation. At the end of this section, respondents were provided with a text box, so they may qualitatively describe additional barriers that may have unintentionally been excluded of the survey instrument.

The authors acknowledge that the survey instrument has some limitations. The survey questions do not capture the description of how the BIM and energy modelers actually used BIM for simulation. For instance, the survey did not ask which specific aspects of a BIM model were used for the energy simulations (geometry only, data only, or both) or if any partial data transfers were experienced due to interoperability issues. Thus, we can only infer if the respondents were

TABLE 3. Engagement classification level (Adapted from McGraw-Hill 2012).

Tier of BIM and Energy simulation engagement (Each-Level)	Range of scores for each E-Level
Very High	27
High	19 to 26
Medium	11 to 18
Low	3 to 10

thinking about the model or the data. In addition, the participants were not asked about which phase(s) energy simulation was performed (conceptual , schematic, design development, etc.), which might impact their perception of the BIM's usefulness. Continued study of the actual BIM-based energy simulation process represents an opportunity for further research.

3.2 Data Analysis Methods

Nominal, ordinal, and ratio data were collected from this survey instrument, leading the researchers to draw from a range of descriptive statistics to examine frequencies, mean, median, and standard deviation, which show dispersion of the results around the mean. Cronbach's Alpha tests were run to determine the reliability of both the BIM and energy simulation engagement score indexes. These two indexes have three categories (experience, expertise, and implementation as shown in Table 2) and the Cronbach's Alpha test allows researchers to measure the strength of that consistency among items in these categories. In addition, bivariate Spearman correlations were performed so that the relationship between energy simulation/BIM engagement scores and respondents' perceptions of the value associated with using BIMs to inform simulation could be observed. The Spearman's correlation test was used because of the nature of the ordinal scales that were used to create the engagement indices. Furthermore, Mann–Whitney U (MWU) tests were run to determine the significance levels in the differences in mean values between different user groups overall perceptions of the value associated with using information from BIMs to inform energy simulation and their perceptions of how accurate the energy simulation is at predicting an actual building's performance.

4. RESULTS

4.1 Sample

The sample population consists of green design stakeholders located in the U.S. that use BIM and/or energy simulation software as a part of their job. For the purpose of this paper a *green design stakeholder* is a person who holds an interest in the design of a project that is slated to achieve greater levels of energy efficiency, produce less carbon and/or minimize environmental impact more than an average building. The sample started as a convenience sample that was then allowed to "snowball" to the contacts of those in the initial convenience sample. The initial convenience sample (consisting of approximately 210) was gathered through a variety of channels including: academics, ENR's Top Green Contractors list from 2011 and 2013, a contact at BIMforum.org and a local sustainability consulting firm. Additionally, respondents were asked to forward this survey along to any of their contacts who met the green design stakeholder criteria. Including forwarded surveys, the number of respondents who received the survey is estimated to be approximately 270.

A total of 85 responses were generated. However, a total of 34 respondent results were removed from analysis because they were either insufficiently complete or because respondents did not meet the criteria of green design stakeholders. The final survey sample size analyzed is 51. Based on a sample size of 51, which came from an estimated sample population of 270, the response rate is estimated at approximately 19%. The breakdown of respondent firm types was comprised of 35% engineering firms, 27% architectural firms, 20% general contracting firms, 8% other, 6% energy consulting firms and 4% construction management firms. As a whole, respondents indicated that 43% of their work was comprised of institutional projects, 39% commercial, 10% residential, 7% industrial and 1% other. Although respondents were located

TABLE 4. Respondents' firm size breakdown by type.

Firm Size	Firm Type	
	Construction Related	Design Related
Small firms	1	4
Small to medium firms	0	18
Medium to large firms	2	13
Large firms	9	4

all over the U.S., the majority were located in Colorado (n = 38), which is a limitation of this study and prevents generalization of the results. The breakdown of firm sizes is outlined in Table 4, showing more of the respondents are professionals from design related firms.

In terms of their professions, respondents held a wide range of roles such as mechanical engineers, project managers, preconstruction, design manager, electrical engineers, and architects. However, the most prevalent responses were from those engaged in the architecture profession. The breakdown of BIM respondent experience was: Less than or equal to 1 year (n = 4, 8%), Greater than 1 year to less than or equal to 2 years (n = 4, 8%), Greater than 2 years to less than or equal to 3 years (n = 10, 19%), Greater than 3 years to less than or equal to 4 years (n = 10, 19%), Greater than 4 years to less than or equal to 5 years (n = 6, 11%), Greater than 5 years (n = 19, 36%). In addition, survey respondents had mixed backgrounds with the software programs that they use. Autodesk Revit and Autodesk Navisworks were the two most widely used BIM software programs by respondents' firms, whereas eQuest and Trane TRACE were the two most widely used energy simulation software programs by respondents' firms. Although respondents who did not use either BIM or energy simulation programs were omitted from the data analysis, the remainder of respondents engaged with BIM, energy simulation or both software programs to some degree. BIM-only comprised the largest segment of respondents, with 24 of 51 (or 47% of respondents). BIM and energy simulation users comprised the second highest group of users with 22 of 51 (43% of respondents) using it, while energy simulation-only users comprised the smallest group of people with only 5 of 51 (or 10% of respondents).

4.2 Analyses

A Cronbach's Alpha test was run on both the BIM and energy simulation engagement indices (broken down in Table 2) to determine how closely related the scale's items (experience, expertise, and implementation) were effectively determining the reliability of each scale. Both scales were determined to be reliable, with a 0.638 and 0.765 Chronbach's Alpha value for the BIM and energy simulation engagement indexes, respectively. Engagement scores are measured on a 3–27 point scale (shown in Table 3). Of the 46 respondents that use BIM, engagement scores varied widely with a mean score of 15.04 and a Standard Deviation (SD) of 6.13. Of all BIM users, eleven fell into the *low* engagement level group, twenty-four *medium*, seven *high* and four were *very high*. Similarly, of the 27 respondents that used energy simulation, the mean engagement score was 15.85 with an SD of 7.66. Of all energy simulation users, eight fell into the *low* engagement level group, seven *medium*, nine *high* and three were *very high*.

When asked the question "*How accurate do you perceive energy simulation in predicting a building's actual operating energy usage?*" on a seven-point Likert scale (one being most negative, four being neutral, and seven being most positive), the average of all responses for this question (n = 50) was approaching *somewhat accurate* (with a mean of 4.66 and SD of 1.12). However, when looked at in distinct user groups (BIM-only, BIM and energy simulation, and energy simulation-only) different trends began to emerge. For example, BIM-only users perceived energy simulation accuracy at predicting actual performance to be the highest with a mean response of 4.87 (SD of 1.014) while BIM and energy simulation users had a mean response of 4.45 (SD of 1.057). However, a Mann–Whitney U test of these means did not show a statistical level of significance (p 0.267), indicating that there was no significant difference between these two user group averages. Despite the lack of statistical significance, this difference in means begins to suggest a trend that BIM-only users might be more optimistic in capabilities of energy simulation programs.

When asked their level of agreement with the statement "*there is significant room for improvement in the process by which stakeholders provide me with information pertaining to the creation of an Energy Model*," respondents (n = 51) were in the range of *slightly agree* to *agree* with an average score of 5.37 for the response group. Similar to the previous question, BIM users had the highest agreement level with this statement with a mean value of 5.59 (SD of 0.959) while BIM and energy simulation users and energy simulation-only users had mean values of 5.33 (SD of 1.167) and 4.6 (SD of 1.949), respectively. Even though the discrepancy between BIM-only users and energy simulation is large, no meaningful results can be drawn because the sample of energy simulation-only users is too small (n = 5).

Additionally, when asked to indicate their *overall Perception of the Value* (PoV) *associated with using information from BIMs to inform energy simulation* (on a seven-point Likert scale where 1 is a *very low value*, 4 is *neither a high nor low value* and 7 is a *very high value*), the mean score of the respondent group (n = 51) was 4.39 (SD of 1.662). Again, when broken down into distinct user groups, BIM-only users had the highest perception of the *value associated with using information from BIMs to inform energy simulation* with a mean of 4.88 (SD of 1.484), energy simulation-only users (n = 5) had a mean value of 3 (SD of 1.871) and BIM and energy simulation users had a mean of 4.18 (SD of 1.651). This also shows that survey respondents who were BIM-only users appear to have the most positive perceptions of the value associated with BIM-based energy simulation.

Initially, the researchers hypothesized that a positive correlation would exist between both respondents' BIM and energy simulation engagement scores and their PoV *associated with using information from BIMs to inform energy simulation*. After running Spearman correlation tests between the variables, the researchers found a weak negative correlation (r = –0.3034) existed between energy simulation engagement and PoV, and a weak positive correlation (r = 0.1498) existed between BIM engagement scores and PoV. By normal standards, the associations between these two variables are not considered statistically significant (p 0.1698 and p 0.3205, respectively). However, when broken down into distinct user groups, the BIM-only user group (n = 24) had a positive correlation (r = 0.4377) and showed statistical significance (p 0.0324) between BIM engagement and PoV. This positive correlation implies that BIM-only users are more likely to have a higher overall perception of the value associated with using BIMs to inform energy simulation as their engagement levels with BIM increase. This positive correlation may also be because BIM-only users become more confident in their ability to produce complete and accurate models that contain all parameters necessary for energy simulations. As

TABLE 5. Breakdown of user group Spearman's correlation between BIM/energy simulation engagement and PoV.

		Energy Simulation Engagement Score	BIM Engagement Score
Perception of value (PoV)	BIM & energy simulation (n = 22)	–0.3034 (*p* 0.1698)	0.1498 (*p* 0.3205)
	BIM-only (n = 24)	—	0.4377 (*p* 0.0324)*

*Correlation is significant at the .05 level

a summary, Table 5 shows the breakdown of different user group correlations between BIM/energy simulation engagement and PoV.

4.3 Perceptions of Benefits and Barriers

Lastly, the researchers investigated green design stakeholders' perception of the benefits and barriers with using BIM-based energy simulation. All respondents identified *facilitates communication*, *reduced process-related costs*, and *ability to examine more design options* as the main benefits of BIM-based energy simulation. Table 6 shows the breakdown of user group perception of benefits items related to BIM-based energy simulation.

The energy simulation-only user group was purposely omitted from Table 6 due to their small sample size of 5. Significance difference at $p < .10$ was found in two of the benefit items, indicating discrepancies of perceptions between these user groups. Interestingly, BIM-only had much higher levels of agreement that *time savings* is a benefit of BIM-based energy simulation than did BIM and energy simulation users. This may be because BIM-only users are only responsible for creating the BIM models, but BIM and energy simulation users have to ensure

TABLE 6. Breakdown of user group perception of Benefit items related to BIM-based energy simulation.

	BIM & energy simulation users (n = 22)	BIM-only users (n = 24)	Significance (Mann–Whitney U)
Benefit Items	**Mean**	**Mean**	*p*
Facilitates communication	5.45	5.08	0.3125
Reduced Process-Related Costs	5.36	4.88	0.0891*
Ability to Examine More Design Options	4.91	5.29	0.6384
Time Savings	4.05	5.04	0.0854*
Increased Accuracy	4.00	4.75	0.1118
Technical Ease	3.64	4.08	0.5687

*Significant at the .10 level (at least 90 percent certainty) that all the correct information is embedded within the model before using it to inform an energy simulation. On average, BIM and energy simulation users perceived that there is greater potential for BIM-based energy simulations to reduce process-related costs than the BIM-only users. This difference may reflect the fact that creating BIM models may be a more streamlined, less iterative process than performing energy simulations. However, the iterate and exploratory nature of performing energy simulation may be seen as an effective way of generating better and more cost efficient design decisions.

Generally, all respondents identified *Lack of BIM standards for model integration with multi-disciplinary teams*, *Learning curve*, and *Software functionality* as the main barriers of BIM-based energy simulation. On average respondents agreed to some extent that all the items listed in Table 7 (aside from "hardware costs") acted as barriers to implementing BIM-based energy simulation, the highest level of agreement was still in-between somewhat agree and agree. Table 7 also shows the breakdown of user group perception of barrier items related to BIM-based energy simulation. Again, the energy simulation-only user group was purposely omitted from Table 7 due to their small sample size of 5.

Compared to BIM and energy simulation users, BIM-only users have a much lower perception of *additional time needed to build a model*, with mean values of 5.32 (above slightly agree) and 4.5 (between neither agree nor disagree), respectively with a significance of p 0.0096.

TABLE 7. Breakdown of user group perception of Barrier items related to BIM-based energy simulation.

	BIM & energy simulation users (n = 22)	BIM-only users (n = 24)	Significance (Mann–Whitney U)
Benefit Items	**Mean**	**Mean**	p
Lack of BIM standards for model integration with multi-disciplinary teams	5.5	5.21	0.2891
Learning Curve	5.32	4.92	0.1141
Software Functionality	5.05	4.79	0.3125
Additional time needed to build the model	5.32	4.50	0.0096**
Interoperability issues	4.86	4.67	0.6455
Training Cost	4.95	4.63	0.2713
Lack of others' capability to collaborate on a BIM model	4.91	4.75	0.7039
Lack of management buy in	4.14	4.96	0.1527
Software cost	4.64	4.29	0.4473
Lack of motivation to change current processes	4.14	4.54	0.4654
Hardware cost	3.68	3.88	0.7114

**Significant at the .01 level (at least 99 percent certainty)

This could be due to the fact that BIM-only users are not completely familiar with all of the information that must be included in a BIM model to create a complete energy model.

Lack of BIM standards for model integration with multidisciplinary teams, *learning curve* and *software functionality* were the only other barrier items that were at or above or at *somewhat agree* for perceived barriers to using BIM for energy simulation, but no statistical significance was found between groups. Despite the literature review mentioning interoperability as a barrier when leveraging BIM for energy simulation, responses, on average, were below slightly agree (4.82) that interoperability is a barrier to BIM-based energy simulation (Hitchcock & Wong, 2011).

Overall, respondents had the highest level of agreement with the statement "*Integrating BIM with energy simulation tools facilitates greater levels of communication among design stakeholders*" as a benefit associated with using BIM-based energy simulation. In addition, respondents highly agreed that "reduced process-related costs" and "the ability to examine more design options" were all benefits associated with using BIM for energy simulation.

5. CONCLUSIONS

The overall goal of this exploratory study was to determine what green design stakeholders perceive as the main barriers and benefits to leveraging BIM for energy simulation and to determine how BIM and energy simulation engagement scores impact green design stakeholders' overall perceptions of the value associated with using BIM for energy simulation. Correlating green design stakeholder perceptions on the value associated with BIM-based energy simulation and BIM and energy simulation engagement scores allows researchers to observe and test if engagement with either (or both) tool is likely to increase their perceptions of BIM-based energy simulation. Specifically, a positive correlation of 0.4377 was found between the overall perception of the value associated with using BIMs to inform energy simulation and their BIM engagement scores for BIM-only users. This correlation might indicate that as BIM-only users become more familiar with using BIM they may perceive higher levels of value associated with using information from BIMs to inform energy simulation, which may be because they become more confident in their ability to construct better models. However, BIM-only users may not know exactly what information energy modelers require from BIM models and may be overly confident in their model's usefulness for energy simulation purposes. Greater training and education along with creating a feedback loop with downstream energy simulators may help alleviate issues that arise from modeling over confidence.

Based on the responses, green design stakeholders' overall perceptions of the value associated with using information from BIMs to inform energy simulation were between *neither low nor high value* and *somewhat high-value* with a mean score of 4.39. Although not statistically significant, when comparing distinct user groups within the respondent pool, BIM-only users had the highest average perception of value associated with using BIM to inform energy simulations (mean of 4.88), while those who only used energy simulation had the lowest (mean of 3). BIM-only users also have the highest perceptions of an energy simulation program's ability to accurately predict building performance with a mean value of 4.87. This comparison suggests that BIM-only users may have overly optimistic expectations of the capabilities of energy simulation.

It was also found that different user groups' perceptions of the greatest benefits and barriers associated with using BIM-based energy simulation varied considerably for some items.

Interestingly, BIM-only users had a much a more positive perception of the benefits of time-savings (5.04) and technical ease (4.75) compared with BIM and energy simulation users at 4.05 and 3.64, respectively. This helps reinforce that BIM-only users may be overly optimistic in their ability to create models that are usable for energy simulators or that energy simulators may only have incomplete or inaccurate models to work with. Overconfidence on the behalf of the BIM-only users may be due to their lack of experience running energy simulations first hand or knowledge of the specific parameters required to run accurate energy simulations. In the field of psychology, this aligns with a cognitive bias referred to as the Dunning-Krueger Effect.

The results from this cross-sectional and exploratory study point out that a need for additional research on this topic exists. The authors acknowledge that a small sample size is a limitation of our study, and while the findings are meaningful, they may not be generalizable. In future studies, the sample size should be larger and more evenly distributed throughout the U.S. and should include more energy modelers so that more significant conclusions can be drawn from their responses. Opportunities also exist to examine demographic data about respondents (such as sex and age) and their working environment (such as type of company, project type, contract type, and level of building performance targeted) in more detail to identify trends that develop from different demographic groups and determine if these factors are correlated to their perceptions.

Although the Cronbach's Alpha test determined the engagement indexes were reliable, new engagement indices could be created to represent engagement levels. Further research on this topic should investigate education level and training experience of the green design stakeholders who use BIM for energy simulation. Additional research could focus on different strategies to get distinct user groups to implement BIM for energy simulation. Lastly, examining in greater detail how those who already use BIM for energy simulation actually utilize information stored in BIM models to inform their energy simulations and the challenges associated with this process could also help develop a richer context for developing a guiding framework for AEC firms to conduct BIM-based energy simulations.

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