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Dynamic Life Cycle Assessment Integrating Cultural Value

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ABSTRACT
Lack of spatial and temporal flexibility is a well-known limitation of current life cycle assessment (LCA). Exclusion of human and time consideration in LCA can also limit the potential of results. This paper explicitly proposes a dynamic life cycle framework and assessment model and demonstrated the potential importance of the method by integrating the cultural theory of risk. Cultural theory (CT) of risk was developed by anthropologist Mary Douglas and is originally a societal social anthropology approach based on the structure and functioning of groups within societies. Different society produces its own selected view of the natural environment, a view which influences its choice of danger worth attention. Applying the set of views of natural environment helps us to understand how occupants behave and make important decisions that produce substantial environmental impacts during the building use phase. Cultural theory results in five archetypes of people: the individualist, hierarchist, egalitarian, hermit, and fatalist. Each archetype reflects a composition of ideologies, cultural biases, social relationships, moral beliefs, and concerns of interest. One of the reasons to apply CT in this LCA research is the fact that the different archetypes can be considered as theoretical constructs that facilitate a comprehensive classification of decision makers in LCA. A case study of an elementary school is used to illustrate the importance of the method and demonstrate the differences between conventional static LCA and dynamic LCA. The results showed a noticeable difference and illustrated some unique environmental impact trends by integrating value choice and human factors in the LCA model. The findings suggest changes during a building's lifetime can influence the analysis results to a greater degree, and that long-term indicators and short-term indicators have different impacts on results. Therefore, adapting a dynamic framework could increase the applicability of LCA in decision-making and policymaking.

KEYWORDS
Dynamic life cycle assessment, school building, value choice

INTRODUCTION
As designers, engineers and building industry practitioners become increasingly aware of the environmental impact caused by building products, building systems and early design decisions, accurate environmental assessment has become important for the building and construction industry to achieve a more sustainable future. Life cycle assessment (LCA) can aid in quantifying the environmental impacts of whole buildings by evaluating materials, construction, operation, and end of life stages, with the goal of identifying areas of potential improvement (Junnila et al. 2006; Scheuer et al. 2003; Kofoworola and Gheewala 2008;Wu et al.2011). Effective improvement and utilization of life cycle assessment in building industry, particularly design phase, hinge upon identifying current barriers that burden LCA. One of the critical barriers is the integration of ever changing factors during the entire life span of a building. Unlike other commercial products, a building has a much longer life span, 50-75

years, and the use phase can have large environmental impacts with multiple renovations and building upgrades related to building technology developments. Variations (such as multiple renovations) within the use phase can sometimes be greater impact than the total impacts of materials, construction, or end-of life phases (Collinge et al. 2013), and the variations are often caused by the users' choice and decisions, human factors. The proposed dynamic LCA framework and model allow the integration of value choice in the LCA of building.

CULTURAL THEORY

Cultural theory (CT) was developed originally as a societal social anthropology approach based on the structure and functioning of groups within societies. Any form of society produces its own selected views of the natural environment, a view which influences its choice of danger worth attention (Douglas 1982). Applying this set of views of the natural environment will help us to understand how people behave and make important decisions that produce substantial environmental impacts during a building's entire life cycle. Douglas argues that the variety within an individual's social life can be adequately captured by the two dimensions of sociality: group and grid. Group is the extent to which an individual is incorporated into bounded units, and grid denotes the degree to which an individual's life is circumscribed by externally imposed prescriptions (Mamadouh 1999, Hofstetter et al 2000). The two dimensions together define an archetype: strong group boundaries along with minimal prescriptions produce *egalitarian*; *hierarchist* is characterized by strong group boundaries and prescriptions; *fatalist* is excluded from group decisions coupled with binding prescriptions; *individualist* is defined by neither group incorporation nor prescribed social roles; *hermit* is the individual completely withdrawn from social involvement. These five archetypes could be understood as perspectives that are taken to view and manage the system, dealing with risks presented from natural disasters or man-made catastrophes. Among the five archetypes, "*fatalist*" will not take long-term or life cycle perspective and take no active role in decision making, and "*hermits*" withdraw from social involvement altogether (Hofstetter et al 2000), therefore, only three are active in public decision-making: the *individualist, hierarchist*, and *egalitarian*. Using CT could help us understand and predict the decisions made by a group of people, a community, or a society. *Egalitarians* have the longest time horizon for building life. They would argue that exposure in the distant future is at least as important as exposure today and society should adjust its needs to limit the exposure of future disasters or risks (Frischknecht et al 2001). The *individualist* views humans as having a high adaptability through technological and economic advancement; therefore, their decision-making will be based on known damage or threats. They concentrate on the present effects over future loss and gain, and their time horizon for a building's service life span is the shortest. The *hierarchist* considers nature to be in equilibrium. They view the present and future as equally important. They seek proper management to avoid future risk and search for a balance between manageability and precautionary principles. Their time horizon for a building's service life span falls in between the *egalitarian* and *individualist* and typically coincides with the current life span used among the building industry which is 60-70 years (De Schryver 2011; Hofstetter 1999). Collectively, the different social groups' views on building longevity and impact are reflected in their approach of pursuing energy efficiency while reducing environmental impact. The *Individualist* group focuses on short-term payback and result, thus site net zero energy is their interest. The *hierarchist* group focus on long-term energy balance and impact reduction, so source energy is their main concern. We could assume different countries could be viewed as collective social groups. For instance, we assume United States is an *Individualist* dominated group, and China is a *hierarchist* dominated group. The different views of the natural environment could result in different, localized approaches to energy conservation and environmental reduction. The understanding of each groups' decision-making mechanism and their view of the built environment could eventually feed into policy making, particularly the policies and regulations in the building industry, since building industry has a profound impact on the natural environment.

METHODS

Figure 1 represents this dynamic LCA framework. Compared to the static method, this proposed framework counts character change along with the time horizon (CT horizon) analysis, which is also discounted based on choice value. Time is influential when a life cycle assessment method is used to estimate the environmental impact of an object. An impact rarely occurs instantaneously but rather occurs over an indefinite period of time. In the proposed framework, instead of allowing only one time horizon, we used a finite time horizon to define the system evolvement through the entire life span. To incorporate the human factor to LCA decision-making, user value choice based on the archetype and the discount rate were used to rank the importance of different parts of multiple objectives. An existing elementary school in the state of Maryland was used as the case study to test the framework and model. Quarterfield Elementary School is a one-story masonry building about 44,000 square feet.

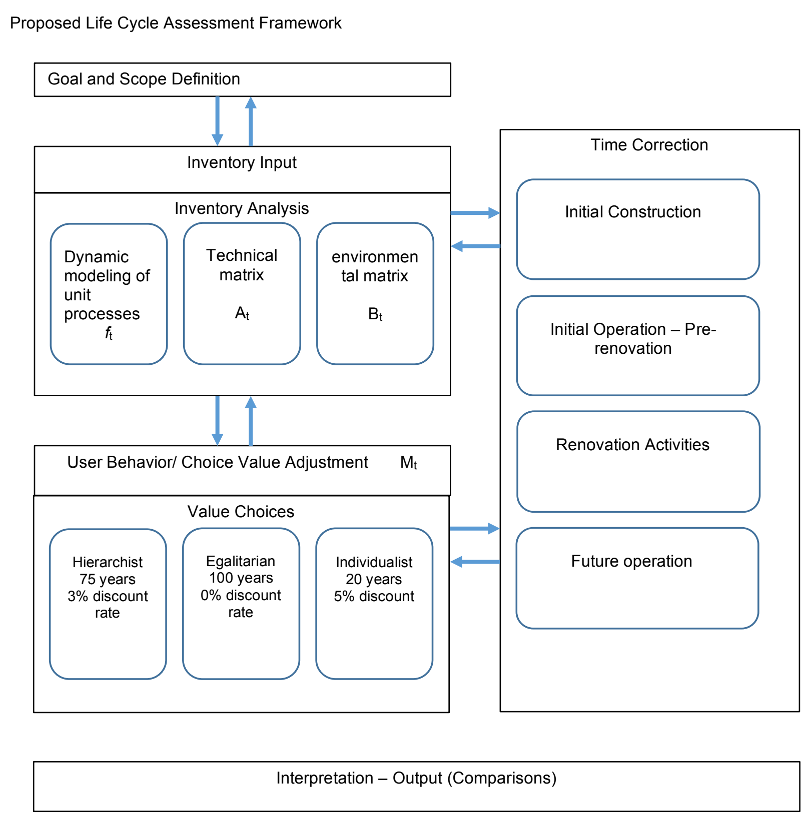

Figure 1 Dynamic framework and model

The major difference between the static model and proposed model is (1) the use of time sequence tables to simulate dynamic variation in matrix coefficients representing modeled relationships. If there is no particular time sequence assigned to variables, then we assume to use a constant value for all time steps; the same as what is used in the static model. The full lifetime in the dynamic model encompasses four time sequences/steps that are explained in Table 1. The future operation includes potential renovation, future operational repair, and maintenance. The second major difference between the models is (2) the adjustment of results through the user's value choice to predicate different scenarios.

Table 1 Time sequence/adjustment included dynamic model

Time Sequences/Steps	Duration	Timeline	Annual Average Energy Usage
Initial Construction (DY-IC)	1 year	1968	
Initial Operation – Pre-renovation (Dy-PA)	23 years	1969-1992	375,400KWh (electricity) 2,4 Million ft^3 (gas)
Renovation Activities (DY-RA)	16 years	1992-2008	319,090KWh (electricity) 2,0 Million ft^3 (gas)
Future Operation (Dy-FO)	35 years	2008-2043	225,240KWh (electricity) 1,4 Million ft^3 (gas)

RESULTS

The results have been normalized to the final static LCA results for each environmental impact category. The categories included in this study are global warming potential, acidification potential, Particular Matter effect on human health (HH Particulate) impact, and ozone depletion potential. The static LCA model was set up based on the original construction documents without any renovation and modification and with a life span of 75 years, which includes the embodied energy and operational energy consumption. The dynamic model was created based on the four time steps explained in table1.: initial construction (year 1), initial operation (before the first major renovation), renovation activities (including multiple renovations across a 16-year life span), and future operation. Figure 2 illustrates the results before integrating the users' value choice. The static model results are higher than the results from the dynamic model in all categories. The largest difference is in the ozone depletion category with the static model projecting more than an 8% higher impact. For the rest of the categories, the acidification potential is 1% higher, human health particulate potential is 2% higher, and global warming potential is less than 1% higher.

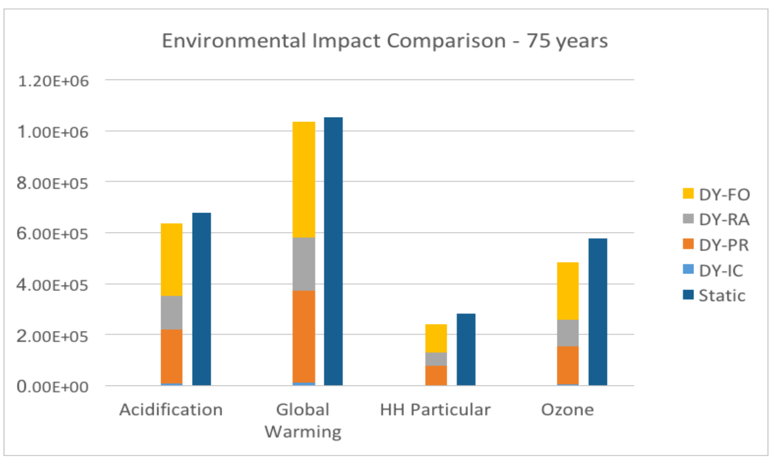

Figure 2 Environmental impact comparison between static model and dynamic model

Three different archetypes have been analyzed and compared. The actual values have been normalized and compared as annual impacts. For egalitarians, the global warming impact takes higher priority. The second and third impacts are the human health particulate potential and smog potential, which could be due to the long-term view of egalitarians and long-term service life span of the building. Those three categories are influenced by long-lived impact indicators, especially those factors particularly related to human health that are embedded in building materials and assemblies, lasting the entire building life. Without discount, the time compounding effect shows a big difference. Hierarchists and individualists have similar impact profiles, with the ozone depletion potential being the primary concern. Most ozone depletion indicators have a relatively short-lived term. Both hierarchists and individualists have shorter building lives with discount; therefore, those short-lived indicators illustrate a bigger impact. Overall, the egalitarian has very different trends from the individualist and hierachist, which indicate that the discount rate factor has a higher impact than life span, meaning the integrating users' preferences and value choices could create very different results from those using the existing static model. For a society or community who holds a long-term vision and an enduring perspective of its future development, paying attention to those long-lived environmental indicators is imperative. If we translate the perspective of building design and construction for building types such as institution, health care, and civic buildings, whose owners and operators are usually the same, then the categories that will contribute the most to environmental impacts would be global warming and human health particulate impact potential.

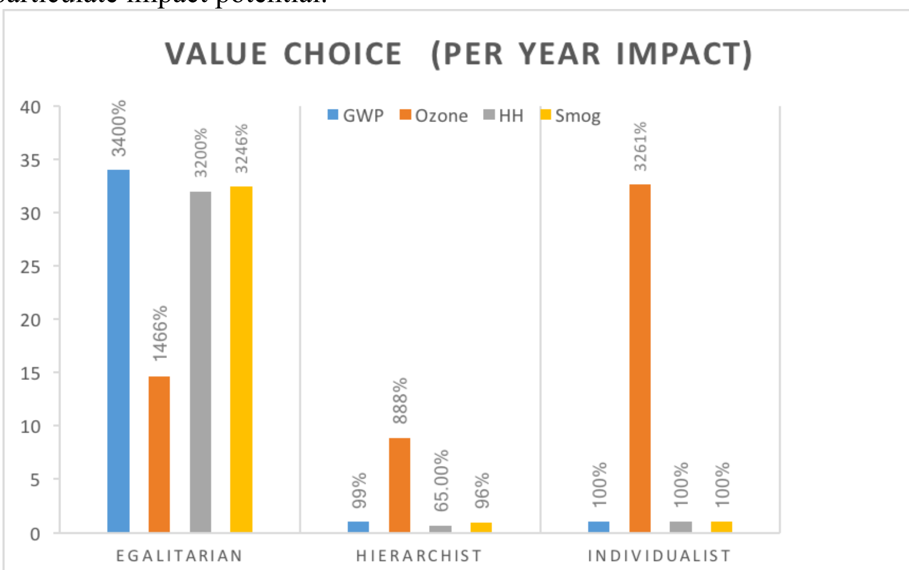

Figure 3 Value choice comparison

CONCLUSION

Therefore, adopting a more dynamic LCA approach, as demonstrated herein, seems likely to provide a more detailed and project-specific projection and equip policymakers and decision-makers with a more accurate and holistic estimation. More importantly, using the cultural theory demonstrated, that the user's choice and cultural context will play a critical part in the LCA of the same building, and the results could vary largely due to the community's and group's perception of building use and tolerance of the risk. In order to fully account for all necessary uncertainties in the LCA study, future research needs to include users and cultural factors, and additional exploration of the interactions with dynamic, temporal, or cultural variables will be very useful to fully understand the environmental impact of individual buildings.

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