SYSTEMS THINKING AND MODELLING FOR BUILDINGS' SUSTAINABLE SITE SELECTION

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Sustainable site selection is considered the first challenging step in the decision-making process for green buildings. It has a progressive effect on the rest of the sustainable categories. Nevertheless, these intrinsic effects are unexploited. Accordingly, this study uses systems thinking and modelling approaches to represent and simulate the feedback loops for proper site selection under 'Leadership in Energy and Environmental Design' (LEED) system. The results indicate that 42% of available points are directly related to site potentials, while 21% are indirectly related- which in sum qualifies the project to the Gold certification level. It also shows dominant and latent feedback loops with other sustainable categories; achieving less energy consumption and water use, promoting the use of green materials and resources as well as providing better indoor environmental quality. Furthermore, it indicates that LEED energy and atmosphere is the most affected category by decisions related to site selection. The presented model sets an objective base for site selection and provides valuable research output for academic and industry outreach.

Keywords: LEED; sustainable site selection; systems thinking, modelling

INTRODUCTION

Selecting building site location is a crucial decision that should consider the whole complex system of green buildings through feedback loops. These would, in turn, carry intrinsic implications on building's energy performance, water use, available green materials and resources as well as providing indoor comfort and air quality. This, in turn, pinpoints the urgent need to develop practitioners' awareness in this regard using advanced knowledge and application of systems thinking.

Leadership in Energy and Environmental Design (LEED) is an internationally and widely applied and accepted building rating system which includes guidance for sustainable site selection within two categories; 'Location and transportation' (LT) and 'Sustainable Sites' (SS). These tackle context and site related aspects, respectively. It is noteworthy that the point scoring mechanism of LEED allows performing quantitative analysis. However, the intrinsic synergies between site selection aspects and other LEED sustainable categories are unexploited which represents a main gap in the existing literature. Accordingly, the author argues that applying dynamic system thinking shall no doubly expand the mental model of decision makers therein.

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Eventually, this shall improve the comprehension of green buildings' performance and discloses intrinsic interrelations of synergies and trade-offs of sustainable aspects; noting that it is practically impossible to act on one factor without affecting the other. This requires a holistic view for their interrelations to maintain their consonance with long term benefit of the entire system instead of individual practices or building elements (Folke *et al.,* 2010; van Kerkhoff, 2014). On one hand, the high leverage points of proper site selection are identified to produce sustainable benefit and catalyse sustained change along the building's life cycle (Gou and Xie, 2017). On the other hand, improper site selection may result in downsizing building performance. These may arise due to an incomplete understanding of feedback loops operating in the system in addition to any side effects which signify flaws and short-sight comprehension of the system's structure, behaviour or feedback loops (Sterman, 2002; Thompson and Bank, 2010). Hence, the site selection process has to be investigated within the various arrays of other sustainable categories to show its influential structure with other sustainable aspects. Accordingly, the LEED system's sustainable guidelines and score weighting mechanism have been used to define parameters which may directly or indirectly be affected as a result of site selection. It is divided into main categories and a number of credits in each. Very few studies have discussed means of assessing the sustainability of sites and fewer have discussed its impact on other sustainable aspects. Building on this conceptual model shall add to the existing body of knowledge for scholars and practitioners to provoke new ways of thinking, acting and responding to building site selection.

Systemic Approach

Recent studies have applied the science of systems thinking as a novel method for life cycle behaviour simulation of sustainable buildings (Marzouk and El-Hawary, 2017). This has highlighted its role for greening residential building stock (Cihat, Egilmez and Tatari, 2014) and as a tool for decision-making in aspects related to building design and operation (Thompson and Bank, 2010). It has also been used to investigate the aggregation of archetype buildings in national building-stock in different European countries and its effect on their energy consumption and carbon emissions (Kalagasidis and Johnsson, 2014; Eker *et al.,* 2018). It is also noted that the application of systems thinking approach allows the integration with Building Information Modelling (Bank *et al.,* 2010; Zou, Kiviniemi and Jones, 2017) and other advanced software programs for modelling problems associated with the building industry. Hence, the Geographic Information System was applied to model building stock data (Bu *et al.,* 2017) and develop an urban level bottom/up model (Österbring *et al.,* 2016).

A number of previous studies have presented modelling approaches and calculation methods for energy efficiency in building-stock (Kavgic *et al.,* 2010; Frayssinet *et al.,* 2018). These have considered factors of building energy use and consumption, emissions as well as cost (Mata, Kalagasidis and Johnsson, 2013). It has also been applied to investigate scenarios of reducing the carbon footprint on the city level (Ercan, Cihat and Tatari, 2016) and to comply with national strategic policies of European countries (Holck *et al.,* 2016). Nevertheless, the effect of location and time change has been rarely investigated in this regard (Fonseca and Schlueter, 2015). Thus, the use of dynamic system thinking is considered an open field of study particularly for solving problems with dynamic complex nature and varying interacting parameters such as green buildings.

RESEARCH METHOD

The research method is divided into three steps; applying systems thinking for sustainable site selection problem, developing the model and finally testing it.

Applying Systems Thinking for Sustainable Site Selection

LEED project checklist and score weighting calculator are used to determine site-dependent credits. This process is performed by the author and double checked by ten qualified independent academics specialized in urban design and planning to ensure reliability and avoid the bias of the outcome results. The intrinsic interrelationships are shown in Fig. 1

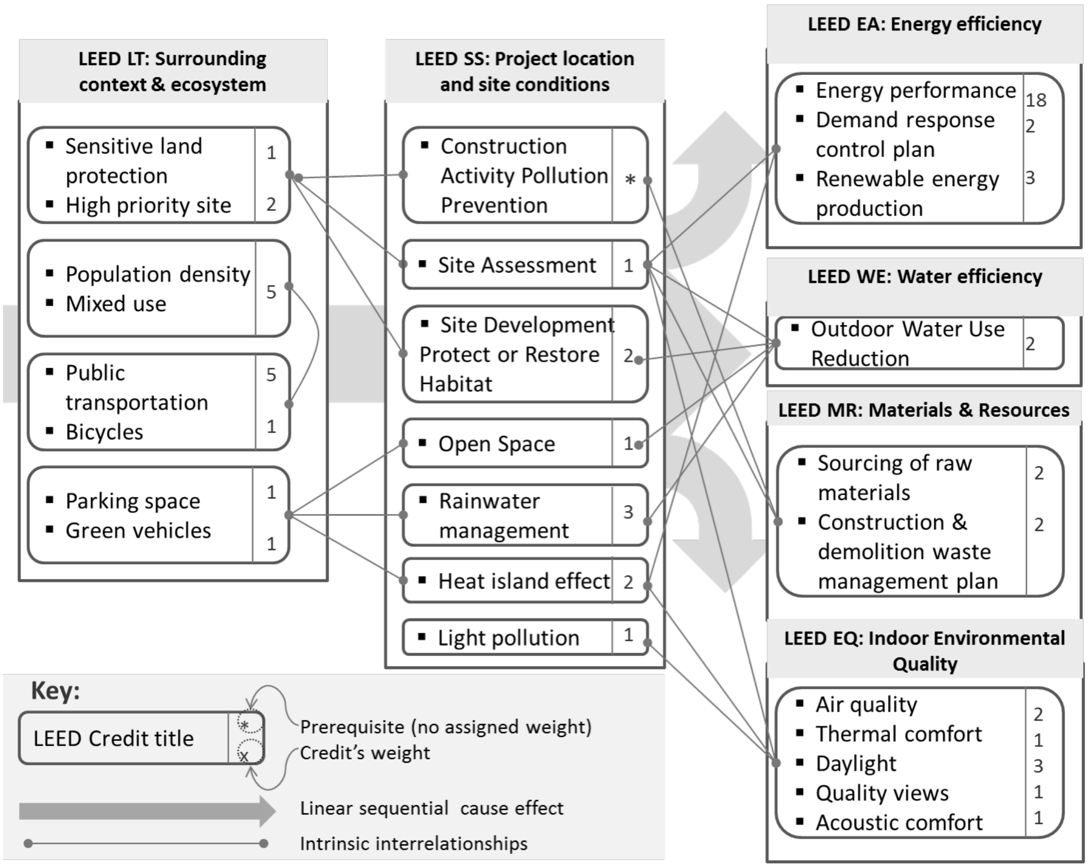

Figure 1: Determining Site-dependent LEED credits

Then, the dependency coefficient of credits and categories in relation to site selection is calculated as a percentage of total available points. Example, Credit: 'Outdoor Water Use Reduction' is assigned 2 LEED points, and credit's content explains the direct connection with site conditions, hence, the study defines it as site dependent-credit, and calculates the dependency coefficient of LEED WE category as total weight of site-dependent credits/ assigned score weight of the category according to LEED checklist, hence, WE is found to be 2/11=18.18%, and similarly for the rest of LEED credits and categories. Hence, LEED main categories; LT, SS, Water Efficiency (WE), Energy and Atmosphere (EA), Materials and Resources (MR) as well as Indoor Environmental Quality (IEQ) were found to have dependency coefficient factors of; 100%, 100%, 18%, 70%, 31% and 50%, respectively. It is noted that LEED for 'Neighbourhood Development Location' credit is excluded to avoid double counting. Similarly, the bonus points assigned for LEED Innovation in

Design and Regional Priority categories have also been excluded because they are awarded according to the project's individual conditions.

Modeling Description

Putting LEED categories in a larger system model establishes a form of combinatorial complexity which requires a detailed investigation of their internal structural components and subcomponents. Thus, using the previous quantitative analysis, a simulation model has been developed using VENSIM PLE software program. This shows the aim of the model, limits of the model boundary, subsystems and feedback relationships.

The target of the model is to investigate scenarios of point accumulation of site-dependent credits under LEED categories with regards to site selection. The model boundary includes main LEED categories (acting as systems' agents e.g. LT) and the subsystems include site-dependent credits e.g. 'High priority site'. Point accumulation has been defined as 'Stocks' where they act as inventories of gaining points over time according to compliance with different LEED credits therein. The rate of point accumulation over time is represented for each category e.g. LT*. Decisions, in turn, alter the rate of flow (increase/ decrease in the stock) of point accumulation in each of the defined categories, altering the stocks and closing the feedback loops in the system.

Furthermore, the dynamic system of complex criteria has been represented in a number of feedback loops-denoted by → upon which their integration determines the level of complexity of interrelated sustainable parameters with those related to site selection over time. These created path dependences (e.g. between High priority site and LT*) signpost positive (synergies) or negative (trade-offs) feedback loops. They also highlight dominant and latent loops affecting the structure and behaviour of the system. This considers the time delay amid deciding on the project's site and its effect on the state of the system. It also indicates irreversible consequences of selecting project's site location which may lead to high leverage points or otherwise the system's resistance throughout the project's development. Hence, in this example, it is a dominant feedback loop which may be positive if the project site has potentials to obtain points under LEED LT category that may lead to gaining points under other LEED credits. It is also considered an exogenous variable because the link to the site potential is clearly indicated.

Testing

Hypothetically, the project development timeline has been represented as points (1-6) where every point represents 2 months of project development on one of LEED theme categories. After developing the model, it has been double-checked for dimensional consistency and model sensitivity in extreme conditions. This is carried out to discover flaws and enable an enhanced comprehension of all related parameters to site selection. Accordingly, two case scenarios have been simulated; LT=0 (01) and SS=0 (02) to test the extreme case scenario of losing points under the LT and SS categories, respectively. The ideal case (reference mode characterized by linear flows of point accumulation and no time delays) represents the state of point accumulation (y-axis) with respect to the project development phases (x-axis). This shows that ideally, the project status allows an initial launching of 16 points owing to obtaining points under the LT category, then, it develops through aspects related to SS, WE, EA, MR and EQ, respectively. For simplification, a sequential process of earning points is assumed; nevertheless, the real complexity arises from the concurrency and interaction of parameters responsible for obtaining points under each of these categories in time. Then, a number of case scenarios have been compared to the reference mode to showcase its effect on other LEED categories.

RESULTS AND DISCUSSION

This research has used the science of systems thinking to study the complexity of sustainable site selection using LEED assessment criteria. It was found that this complexity does not only arise from the two involved LEED categories (LT and SS) in isolation but their interaction with other sustainable categories (WE, EA, MR and IEQ) over time and space as shown in Fig 2.

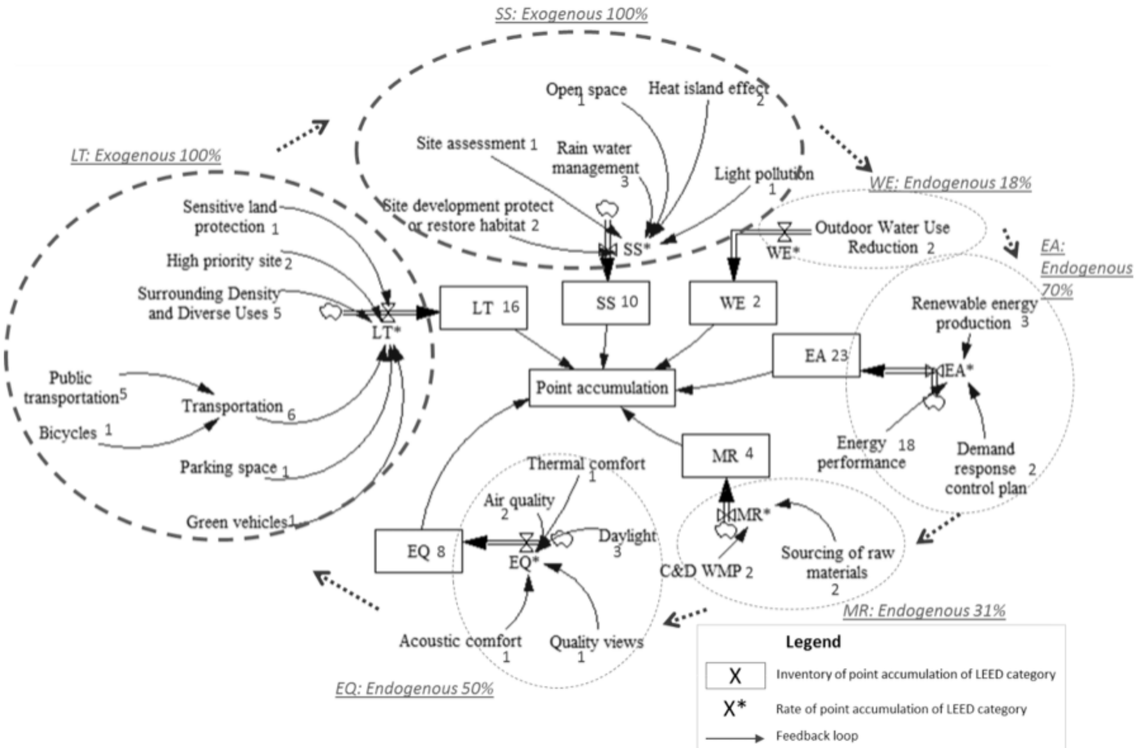

Figure 2: Mapping system structure using the stock and flow model of Vensim PLE software program

Studying these intrinsic relations reveals that proper site selection may earn the project 63% of total available points which qualifies it to the Gold certification level (the second highest level awarded) as shown in Fig. 3. Both LEED LT and SS categories are considered exogenous variables to site selection, while other sustainable categories can be considered endogenous factors with varying degrees; the EA category is the most dominant feedback loop in this regard. These create positive dependency paths between them which directly affect the building performance. Comparing the two case scenarios of extreme conditions to the reference case is shown in Fig. 4. It shows that the rate of point accumulation in the case of LT=0 affects the overall initial project's score weighting but it does not possess the same influence compared to the case when SS=0. This indicates that the project's site-related aspects have direct relationship to other sustainable categories more than its contextual location.

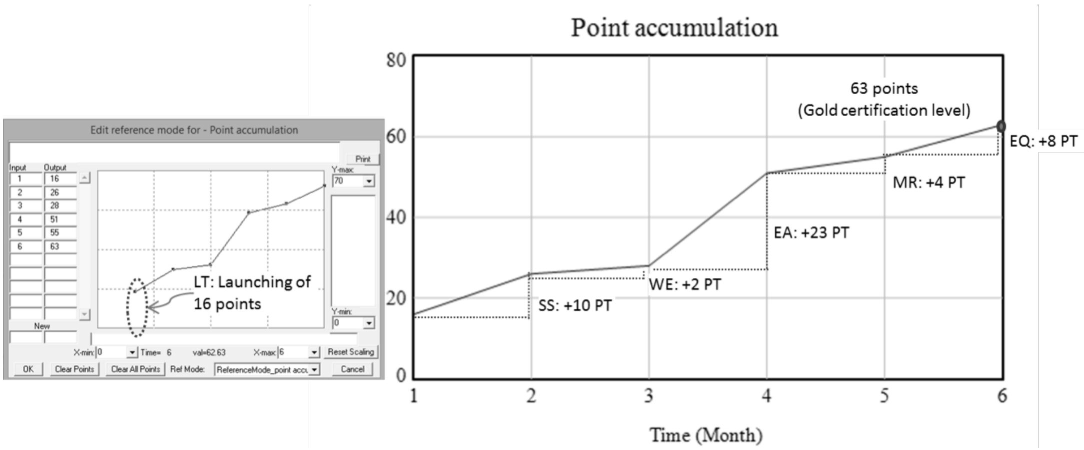

Figure 3: The reference mode for the rate of point accumulation of different LEED categories over time (assuming 12 months project time completion from start to finish), developed from Vensim PLE software program

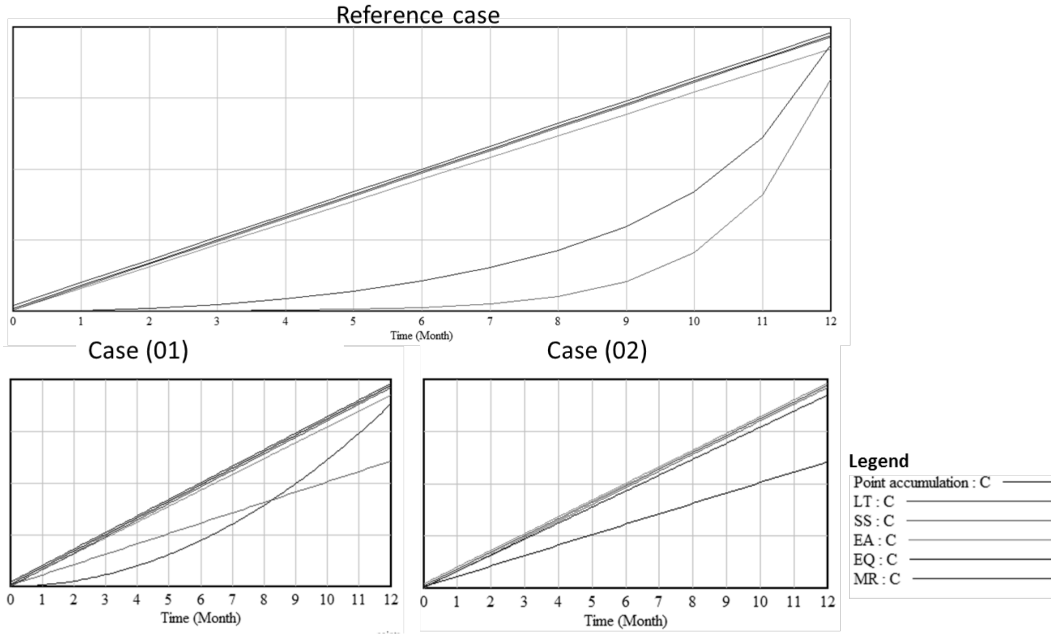

Figure 4: Reference case, two case scenarios, LT=0 (Case 01) and SS=0 (Case 02), developed from Vensim PLE software program

CONCLUSION

This study provides a useful heuristic for conceptualizing buildings as dynamic systems pointing out the effect of site selection. The model adopted in this study presents a pilot attempt to apply systems thinking and modelling approaches to formulate a basis for understanding the challenges associated with a project's site selection. This should be integrated into early project phases to establish an iterative process of joint inquiry that would, in turn, develop a new understanding of the complexity of this problem.

The presented model shows a significant relationship between the structure and behaviour of any sustainable building in terms of the effect of proper site selection on other sustainable parameters. This also reveals dominant and latent feedback loops during project development which would, in turn, affect the patterns of point-gaining of LEED categories and alter the system's response therein. It has been more significant for LT and SS categories (exogenous variables) which have direct relationships to site selection. Furthermore, other indirect relationships have also been revealed; with EA, IEQ, MR then WE categories (endogenous variables).

Finally, it is interesting to note that there is no wrong or right in system modelling, the model is usually assessed according to how appropriate it has addressed the aims and objectives of the study. For this investigative level of study, it is believed that it has reached an appropriate level of completeness; nevertheless, for advanced levels of research, the combinatorial complexity of feedback loops for site-dependent credits may be taken to further detailed subsystems' levels. It would also allow researchers to define internal high leverage points and consider the distant behaviour in time and space between cause and effect which may occur at varying interacting time scales.

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