AN AGENT BASED MODELING AND LIFE CYCLE ANALYSIS BASED APPROACH FOR ENHANCING CONSTRUCTION SUSTAINABILITY IN QATAR

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ABSTRACT

The inevitable global challenges in resource adequacy and pollution facing society is leading governments to consider creating building sustainability regulations and policies that motivate stakeholders to adopt sustainability in construction industry. However, research seeking to rationalize such approaches is still required. This paper presents a framework for developing an Agent-based model composed of two modules that can be utilized to enhance sustainable practices and policy making in the Qatari construction market. In order to create this model, agent attributes, behaviors, and relationships are developed based on surveys of professionals in the Qatari construction industry. The proposed model would be capable of (1) specifying target sets of sustainability rating credits that can meet pre-defined certification levels for projects; and (2) conducting life cycle assessments for the specified sets of credits to calculate the net impact of such projects on the economy and the environment. As a result, this model is expected to be used as a decision support tool for practitioners and policy makers to assist them in maximizing the positive impacts of implementing building sustainability.

Keywords: Building construction, Sustainability, Agent Based Modeling, Life Cycle Assessment

1. INTRODUCTION

The construction industry is characterized, among other industries, by the huge number of materials, processes and technologies that are incorporated within its activities. Warnock (2007) explained that the complexity of building construction is clearly manifested by the various physical components incorporated in those projects. These components result in numerous outputs, and necessitate the coordination of many project aspects that have various demands. Due to this inherent nature, the construction industry stands as a major player in both consumption of resources and impact on environment. The United Nations Environmental Program (2002) revealed that this industry consumes 40% of Europe's energy in addition to its large contribution to the emission of greenhouse gases in the United States.

This impact is even more intense in Arabian Gulf countries due to two main factors. First, the area is rapidly developing in various social, educational and governmental aspects. This development is currently causing a rapid surge in construction projects ranging from mega governmental developments to small private buildings. According to Pratap (2012), an "expected 4.7% compounded annual growth rate (CAGR) in Qatar's population between 2011 and 2016, is likely to translate into higher demand for properties during the period". Many of these projects are being executed within short time spans causing the challenge to sustainability to be magnified. Secondly, sustainability codes and regulations that govern or guide practices in ongoing construction projects are still being developed. Al-Saadi (2010) has identified the need for exploratory research to cross the gap that exists in the domain of sustainable technologies and practices in the state of Qatar. This is gap is exasperated by the lack of data and statistics about the performance of materials and processes. Therefore, it is evident that efforts are acutely required to rationalize sustainable policies and regulations in the construction industry, which would eventually help reduce the inescapable sustainability challenges caused by this important sector of the economy.

2. BACKGROUND

The state of Qatar is taking advanced steps towards adoption of sustainable policies and practices in the construction industry. This movement stemmed from the Qatar 2030 visionary plan, which has identified environmental development as one of the four main pillars of Qatar's National Vision (GSDP 2008). Sustainable development has been specifically stressed in this vision paving the road for Qatar's remarkable efforts to encourage the adoption of sustainability concepts in the construction industry. One of these pioneering efforts is the development of a rating system called Qatar Sustainability Assessment System (QSAS) by the Gulf Organization for Research and Development (GORD). GORD has reviewed and evaluated a number of established international rating systems worldwide like LEED, BREEAM, CASBEE and others to develop QSAS with the objective of making it suitable for the Qatari economical, environmental and social context. This strategy shall be fostered by a significant step that was announced by the Qatari Ministry of Environment during a recent seminar held by Qatar Science and Technology Park on sustainability (QSTP 2012). This step is that QSAS certification shall be gradually required through building permit procedures on building construction through a six year plan starting 2012.

Since the main objective of such policies is the maximization of certain outcomes (sustainable practices in the construction industry in this instance), they can be genuinely supported by Agent-Based simulation models that would help decision makers foresee the impact of each policy on the construction industry and fine-tune their decisions accordingly. North and Macal (2007) have described Agent Based Models (ABM) as simulation tools used to depict the reactions and interactions of the different system components, called agents, based on the system inputs leading to outputs that can be reported to decision makers. The agents in ABM, according to Beheiry et. al. (2006), are autonomous adaptive entities that have attributes enabling them to take decisions on their own and interact with other agents. The interactions between agents are defined in terms of rules that govern these relationships. The simulation of construction processes using ABM has been proven to be very promising tool in process mappings assisting in decision making (North and Macal 2007). One example of these construction models is the one developed by Watkins et al. (2009) to study construction labor productivity as an emergent phenomenon resulting from individual and crew interactions. Palaniappan et. al. (2007) has also simulated safety as an agent based phenomenon in construction site. On the construction project management side, Ren et. al. (2001) has proposed use of agent based simulation to improve the efficiency of resolving disputes during construction.

The objective of this paper is to present the development of a framework for an Agent Based Model simulating important aspects of sustainability in the Qatari construction industry. The model is designed to map the process through which QSAS credits are selected to achieve specific target certification levels. Structured interviews were conducted with a representative sample of key personnel representing developers, consultants, and contractors, to understand the selection process and come up with realistic behaviors. To evaluate the impact of each selected credit, a Life Cycle Assessment methodology is used. This evaluation is meant to be presented in quantified environmental impact figures for comparison purpose. Results of the model can be used for different purposes at various decision making levels by governmental decision makers as well as project stakeholders as shall be detailed in the conclusion and discussion section of this paper.

3. MODULE 1: SELECTION OF QSAS CREDITS TO ACHIEVE CERTIFICATION LEVELS.

3.1 SAS Evaluation Methodology

Before we present the developed framework, QSAS shall be briefly introduced. QSAS credits can be classified into 8 categories, which are used to evaluate the sustainability performance of each project. In QSAS, certified sustainable projects are awarded from 1 to 6 stars based on their overall score that spans from 0 to 3 points as shown in table 1. This overall score is achieved by multiplying the score achieved in each of the 8 categories, whichever is applicable to the building type under evaluation, by the weight allocated to each category. As illustrated in the QSAS Design Manual for commercial buildings (as an example) (GORD 2010), the eight categories are:

1- Urban Connectivity (UC)
2- Site (S)
3- Energy (E)
4- Water (W)
5- Materials (M)
6- Indoor Environment (IE)
7- Cultural & Economic Value (CE)
8- Management & Operation (MO)

Table 1: Certification Levels of the QSAS (GORD 2010)

Score	Certification Level	QSAS Certification
$X < 0$	-	Certification Denied
$0.0 \leq X \leq 0.5$	★	Certification Achieved
$0.5 \leq X \leq 1.0$	★ ★	
$1.0 \leq X \leq 1.5$	★ ★ ★	
$1.5 \leq X \leq 2.0$	★ ★ ★ ★	
$2.0 \leq X \leq 2.5$	★ ★ ★ ★ ★	
$2.5 \leq X \leq 3.0$	★ ★ ★ ★ ★ ★	

QSAS has specified different sets of criteria under the above categories for evaluation of different types of buildings (i.e. commercial, residential, schools, hotels, etc…). The score for each category is obtained through calculator sheets and tool kits designed for each credit. Only companies who subscribe and pay the relevant fees are allowed access to the QSAS documents starting from design guidelines (providing design hints to designers), design assessment manuals (providing general information on how the evaluation is performed for each credit), to calculators and tool kits. However, the philosophy and mathematical assumptions used to develop the calculators are considered proprietary and are not disclosed.

3.2 Agents, Attributes, and Model Inputs

As illustrated in our brief description to QSAS, the project stakeholders have to decide which credits are to be addressed in order to achieve the required certification level. Nookala (2011) developed an agent based model to map the interactions between stakeholders in a construction project leading to selection of credits, based on the Leadership in Energy & Environmental Design (LEED). While Nookala's model aimed at reflecting how the objectives of each stakeholder would affect the credit selection process, the present framework aims at mapping the trends of stakeholders in the Qatari construction market that drive the process of selecting QSAS credits. The first step in developing our framework is to identify the agents representing the stakeholders. Agents represent the main players with ability to influence the credit selection process, which are as follows: Agent 1: Developer; Agent 2: Designer; Agent 3: Contractor; Agent 4: Project; Agent 5: Authority. In order to understand the process of selecting credits, a number of structured interviews were carried with a sample of the industry professionals representing the participating agents. The interview included Likert scale questions for comparison and statistical purposes. These were in addition to open ended questions to allow flexibility for interviewees to elaborate on selection approaches. A sample of the questions asked in all interviews is shown in Figure 1.

For each of the following questions, please select the response that reflects how you feel where 1 = strongly disagree; 2 = disagree; 3 = neither agree nor disagree; 4 = agree; 5 = strongly agree

01. To developers/consultants: cost is a critical factor in deciding the credits to be gained in order to achieve the required certification level. ○ ○ ○ ○ ○

08. To Contractors: if there is no sustainability requirements in a specific contract, your company will still target implementation of some sustainability concepts. ○ ○ ○ ○ ○

12. The highest scores among credits are the first credits to be targeted. ○ ○ ○ ○ ○

13. What is the most critical category (out of the 8 QSAS application areas) with respect to impact on Qatari environment? Why?

20- Based on your experience in Qatar or Middle East, rate the following 8 credit categories with respect to their impact on the given criteria: (1 is the lowest impact while 8 is the highest)

	Urban Connectivity	Site	Energy	Water	Materials	Indoor Environment	Cultural & Economical Value	Management & Operation
Cost								
Construction time								

Figure 1: Sample of the questions from the questionnaire used in the structured interviews.

In light of our analysis of the interviews results, we have assigned attributes to each type of agent reflecting the significant characteristics that will impact the selection process, which constitutes the second step in the development of our framework. Examples of the agent attributes are listed below with discussion of their expected effect on credit selection:

- The Client agent type could be either "Governmental" or "Private". This will affect the directives to designers. Governmental clients would focus on the categories having highest positive impact on Qatar's long term economy, environment conditions and cultural values. On the other hand, private clients would seek to secure the certification through the credits scoring the highest values and are easiest to collect.
- The project agent location could be either "Close to Downtown" or "Away from Downtown". This would have a direct impact on selection of the Urban Connectivity credits especially in case of governmental clients or major private ones. Contract type is another attribute for the project. It could be either "Design-Bid-Build" or "Design & Build". In the later case, contractors will have the flexibility to suggest credits to be addressed and this would lead to selection of credits with least impact on cost, an approach clearly manifested by interview results.
- Consultants could be "Experienced" or "Not Experienced" with respect to designing projects with sustainability certification. Here LEED certification can be considered as a relevant experience since there is considerable similarity between the LEED and QSAS in terms of categories and definition of credits.
- Contractors experience could be viewed in regard to their having Documented Health, Safety and Environment (HSE) Plans or "No Documented HSE Plans". This criterion would lead to some credits to be accrued by default, in case of having HSE Plans, over and above the credits that shall be satisfied in a design-bid-build contract.

The inputs required by this module for every run include the following:

1- Developer's Attributes (Governmental & Private)
2- Project parameters including location, budget, contract nature, etc….
3- Consultant's attributes (Experience, etc…)
4- Contractor's attributes (Experience, Having HSE documented plans, etc…)

The simulation environment includes one passive agent that includes the authority approving project certification documentation but does have an influence on selecting credits. Part of the environment is the QSAS credits, which the agents (basically the consultant and contractor) shall select from. Figure 2 illustrates how the various model components are included in this framework.

3.3 Agent Behaviors and Output

The fourth step is to identify the behaviors governing interactions between agents and their relations with the defined attributes. Both the attributes and the behaviors of the different agents are implemented in the simulation tool kit adopted for this model, which is the Repast Simphony tool kit. The reason behind selecting this simulation tool kit shall be explained at the end of this section. Examples of the behaviors of the developed agent include:

- If the contract is design-bid-build, then the consultant shall be the driving entity in selecting the credits.
- If the developer is governmental and the contract is intended to be design-bid-build, then the consultant shall be focusing on the credits with highest impact on long term economy and environment, which best serves the interests of this type of client. The rating of credits with respect to these criteria shall be created by the statistical analysis of our structured interviews with industry professionals.
- If the location of the project is downtown Doha, the consultant shall give UC (Urban Connectivity) category a higher priority in selection.

- If the contractor has a well documented HSE plans taking into consideration sustainability measures, such as waste management for instance, the output credit selection shall include some extra credits not necessarily covered by the certification, but still contributes to the overall sustainability level of the project.

It's very important to note that this is framework development describes a single project unit. However, the framework is designed to be extendable in order to allow full coverage of multiple projects in the construction market as shall be discussed in the conclusion section.

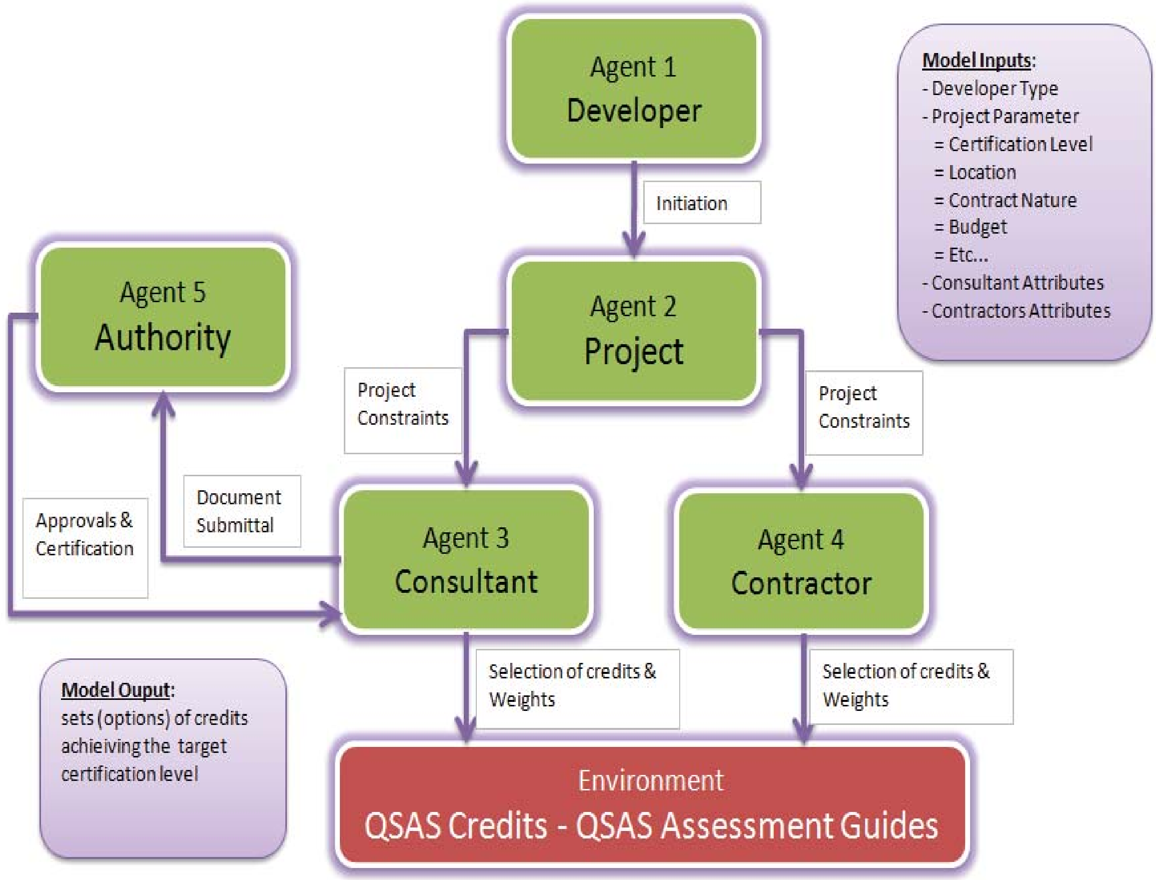

Fig. 2: Module 1 Diagram

4. MODULE 2: LIFE CYCLE ASSESSMENT FOR QSAS CREDITS

The objective of the second module is to provide an assessment of the selected credits in the first module through the use of Life Cycle Assessment in order to reach quantifiable measures to the impact of utilizing such credits. The main motivation behind this approach is to utilize the powerful analytical capabilities of LCA together with the dynamic nature of Agent Based Modeling to serve decision at different levels. Davis (2007) has used a hybrid model combining LCA and ABM using a case study on bioengineering, where the technologies were represented by agents. Humbert et. al. (2007) has recommended using LCA to evaluate LEED credits and carried out this evaluation on 45 credits applied to an actual commercial building in California. The approach adopted in our second module of the model to serve sustainability objectives in Qatar will be detailed in the following description. As will be illustrated, this model can be used by the designers to optimize their selections of credits. It can also be used as a module or sub-model in a large scale ABM for helping policy makers in assessing the impact of selected policies.

4.1 Life Cycle Assessment

Life Cycle Assessment is a technique used to analyze the "Cradle to Grave" impact of using specific product or process on the environment and human health. According to ISO standard 14040 issued by the International Standards Organizations (ISO 2006), the analysis takes into consideration the impact of all processes involved in extracting, manufacturing, transportation, site installation, and the operation till disposal, of such materials on the environment and use of resources. As indicated in this definition of LCA, extensive efforts are required to calculate the impact associated with all the mentioned processes for one material through the four steps defined in the reference ISO standard. These steps are: the goal and scope definition phase, the inventory analysis phase, the impact assessment phase, and the interpretation phase. As illustrated by Trusty et. al. (2005), several databases have already been developed worldwide to serve this purpose. Examples of these databases are Athena in USA, Ecoinvent in Switzerland and GaBi in Germany (Sharard 2007). There is currently no database for Qatar or the Arabian Gulf region as a whole.

4.2 LCA Module

As indicated in our model introduction, the input to this module is actually the output of the previous one, which is set of two or more options of QSAS credits that can achieve the target project certification level. The module could therefore also compare the impact of different sets of credits, which could be a useful tool for decision makers at different levels of the construction industry. In fact, this type of assessment enhances and guides the conventional wisdom and the rationale behind credits that are selected through a fully objective and quantitative analysis of the performance of each material or process used. To clarify the procedures of this module, let's assume that a designer is targeting 70% of the score under the materials category of the QSAS in order to attain a certain certification level and this can be achieved by various combinations of credits under this category. The question is: which combination shall serve the environment better? This can be answered by analyzing the life cycle impact of the elements addressed under each credit and hence optimizing credit selection.

The components for this module, as shown in figure 3, are the project, the credits, the LCA Evaluator and the LCA database. The project will be described by the project scope of works and critical parameters. Typically, this is taken from the Work Breakdown Structure of the project and the construction method statement. The credits here are part of the environment, where each credit is built according to the QSAS design and assessment manuals. Each credit shall evaluate their respective project parameters and identify the materials and processes that can be identified by the LCA evaluator. This is a very critical stage in the modeling process since every credit has its own approach in calculation. Therefore, for each credit, the materials and processes that are relevant and can be accessed from an LCA perspective are identified. The next component is the LCA evaluator, which basically acts as a calculation tool that communicates with credit and the LCA database to calculate the impact of each option. To illustrate how the LCA calculator works, let's assume that use of credit X will lead to saving of a hazardous material Y by a certain amount. The LCA database, built in our model, has information on the environmental impact associated with the use of material Y. This information, typically, is represented in terms of quantifiable amounts of impact indicators (such as Co2) under multiple impact categories (such as global warming). Our LCA calculator is the model component that will be reading such impacts from the database based on the material or processes associated with each QSAS credit. It will also add all the impacts to show one list representing the environmental impact of implementing the select credit or set of credits.

The last component in this module is the LCA database that is the primary source of data for the LCA evaluator. The database provides the environmental impact of each material processes identified by the credits, which is represented in form of impact indicators under multiple impact categories. This information is accessible and read by the LCA evaluator, which compiles all impacts for each credit or set of credit and calculates the overall impact for comparison purpose.

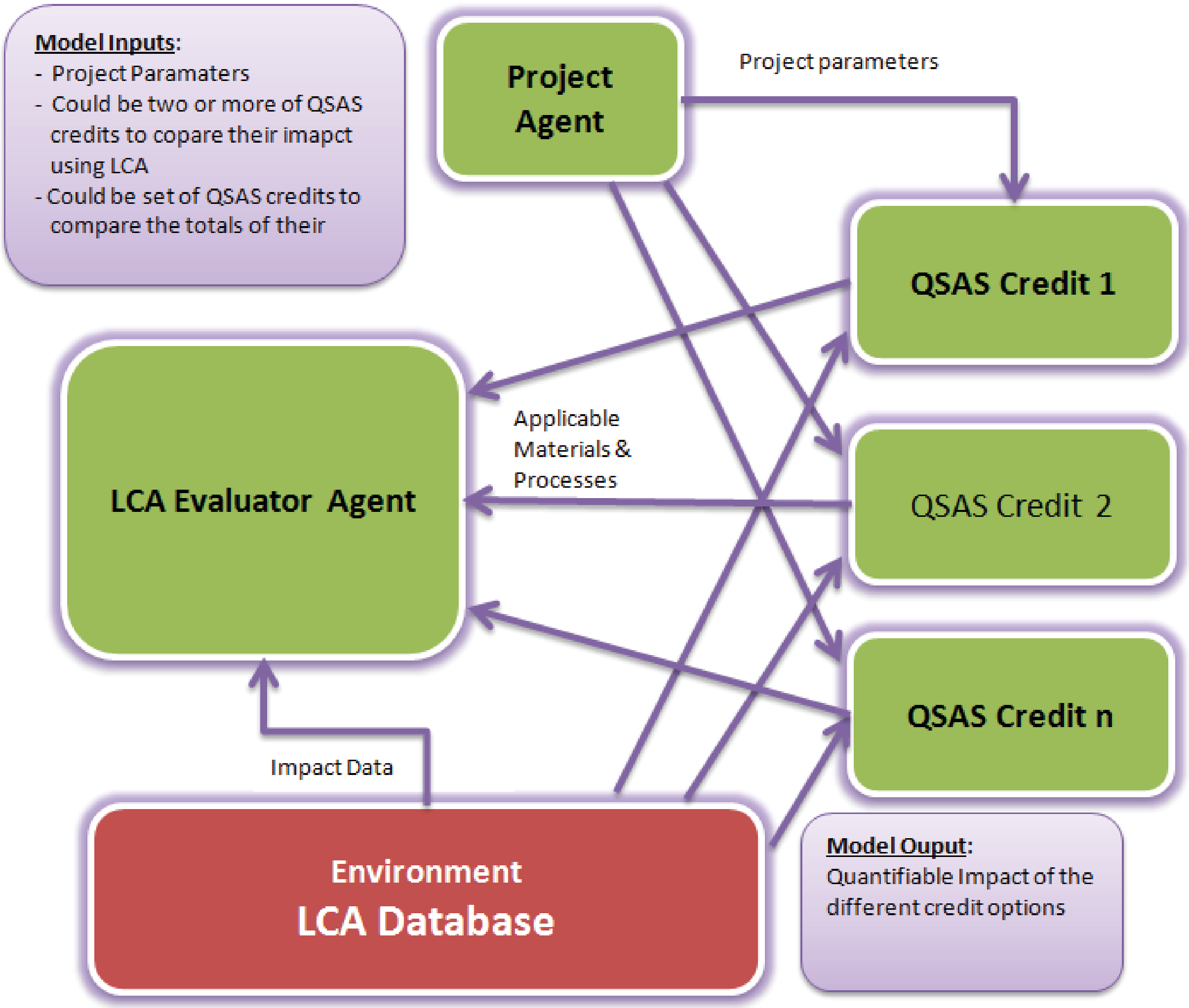

Figure 3: Model 2 Diagram

5. DISCUSSION

The model covers two aspects in implementation of sustainability in construction in the state of Qatar. The first is the selection of credits that would achieve QSAS certifications based on the priorities perceived by projects stakeholders including clients, consultants and contractors. This part of the model acts as a process mapping of the selection methodology as practiced by experts in this field. It can also be used by practitioners as an assisting tool in the credit selection process for a new project as it will result in selection of credits that are perceived of high significance among others. The main limitation of this module is that the priorities and selection directives were based on input from sample of the construction industry stakeholders not based on a survey of the whole construction market. The sample included 25 companies representing contractors, consultants and developers, which were selected among the key players of the Qatari market. However, we believe that more interviews can be done in the future to verify the trends of selections identified in this research.

second module is a tool to be used by practitioners to rationalize the selection process and optimize the positive effect on environment and use of resources. The tool can also be used by QSAS to reevaluate the weights assigned to each credits based on a more scientific approach. The main limitation of this module lies in the relevance of the LCA database, to be selected, to the Qatari conditions. Since there is no LCA database yet developed for the state of Qatar, we will be using one of the international databases. Once a customized database is developed for Qatar, the module can modified to include the new one. The LCA calculator in this case will have to be adjusted to read the data that are relevant the new LCA from the selected credits.

The two modules are also perceived as components of a future overall Agent Based Model that will be compiled to gauge the impact of implementing sustainability policies in the construction market in Qatar. The input to this overall model shall be a certain policy under consideration. This policy will affect the market and the adoption level of this policy in the market shall be measured through a separate module, whose scope is not addressed in this paper. The two modules discussed here, will then be used to assess the impact of this policy adoption on a project level with the aim of presenting the impact in numeric values that can be used for comparison purpose and therefore for guiding a more informed decision making.

6. CONCLUSION

The existing sustainability rating systems stand as a controlling and motivating guide for construction stakeholders to adopt and implement sustainability concepts in their projects. However, there is still a need to rationalize the use of these rating systems with the objective of optimizing the positive impact on the environment and human health. These optimization and rationalization efforts need to be based on an objective quantitative approach to evaluate the relative importance of credits to be selected. In this paper, we presented a framework for an ABM model composed of two modules. The first is for an Agent Based Model capable of identifying set of QSAS credits that would meet target certification level for a certain project. The second module uses the LCA technique to assess the selected credits by quantifying their impacts for comparison purposes. The framework is believed to be useful for practitioners in sustainable design in comparing different sets of credits and choosing their optimum combinations. Another use for these models is to possibly improve or adjust the weighting of QSAS credits, and possibly credits in other rating systems as well, with the objective of achieving the optimum project environmental impacts. The future research efforts needed in this area include the implementation of a multi-scale model based on this framework that evaluates the environmental impacts of sustainable projects in a specific region, such as the state of Qatar. Additionally, further research is clearly required in the direction of creating a regional LCA database in order to make the model outputs more relevant to local context of state of Qatar and the gulf region.

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