A FRAMEWORK FOR MODELING THE ADOPTION PROCESS OF CONSTRUCTION SUSTAINABILITY POLICIES: AN AGENT-BASED SIMULATION APPROACH

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ABSTRACT

Over the past two decades, several nations have undertaken ambitious plans to minimize the ecological impact of their construction industries by developing and promoting sustainability policies. In this respect, Qatar, a country that is experiencing a substantial growth in its construction industry, has taken significant steps among which was developing its own sustainability rating system (QSAS) that is designed to assess and certify the environmental friendliness and energy efficiency of construction projects. This paper presents a framework, developed and currently being used by the authors, for building an agent-based adoption model that can explain the process and predict the rates of the adoption of sustainability policies in the State of Qatar. The model will enable simulating and evaluating various scenarios by determining the influence of different sets of sustainability policies on fostering the overall adoption patterns and rates. This model will allow decision makers to determine the most appropriate policies that can result in achieving the targeted adoption patterns.

Keywords: Agent-based modeling, Sustainable development, Sustainable Construction, Diffusion

1. INTRODUCTION

The building sector is notorious worldwide for its heavy consumption of the planet's natural resources. It is recognized as a major contributor to the deterioration of the environment due to the significant amounts of greenhouse gases emitted and waste generated throughout a building life-cycle. To quote just a few figures demonstrating the foregoing statements, it is reported that, in the US, the building sector consumes a whopping 40% of materials extracted every year. It also consumes 30% of all primary energy and creates every year more than 145 million metric tons of waste, which amounts to one-third of the materials landfilled annually (Kibert 2002). Worldwide, the building sector is responsible for emitting around 40% of the greenhouse gases known for their detrimental contribution to the environment (UNEP 2003). In Organisation for Economic Cooperation and Development (OECD) countries, construction leads to around 25-40% of the final energy consumption (OECD 2003). On the other hand, the situation in non-OECD countries is even worse as the environmental impacts of the building sector can also result in public health issues, especially in urban areas (Melchert 2007).

Moreover, the building sector plays a pivotal role in the economies of nations. Its market volume worldwide is estimated at over USD 3 trillion which is around 10% of the GDP of the world. In comparison to other sectors, the building sector is the biggest in Europe (10-11% of GDP) and the US (12% of GDP), as well. In addition, this sector provides around 7% of the world employment and accounts for more than half of the national capital investments in most countries (UNEP 2003).

With the rise of the environmental awareness and because of the significance of the building sector and its heavy contribution to the environmental degradation, several nations have been undertaking significant efforts to promote the concept of sustainable construction. As quoted in Kibert (2001), sustainable construction can be defined as "creating a healthy built environment based on ecologically sound principles". Sustainable construction typically considers the total life-cycle of a construction project starting from the planning and design stages, and ending with the end-of-life fate of the materials used; construction, operation and retrofitting stages are likewise given equal attention (Kibert 2001).

In order to guide and regulate the adoption of sustainable construction principles, some governmental, as well as, non-governmental entities have developed their own sustainability guidelines (also known as green building guidelines) and sustainability rating systems. Prominent examples include LEED developed by U.S. Green Building Council (USGBC), BREEAM developed by the Building Research Establishment (BRE), and CASBEE developed by Japan Sustainable Building Consortium (JSBC). It is noteworthy that some of these guidelines and ratings systems, most notably LEED, have proliferated beyond their countries of origins and nowadays a plethora of certified projects can be found in many regions around the globe. Examples of projects worldwide that have achieved LEED certification can be found on USGBC website (USGBC.org).

One of the emerging entrants to the green building guidelines field that decided to follow the footsteps of some twenty, mostly developed, nations is the State of Qatar. In 2009, Qatar Sustainability Assessment System (QSAS) was deployed; a rating system which resembles some of LEED's aspects but, in comparison to other systems, attempts to respond to the identified needs of Qatar and its environment. Since its deployment, Qatar, through the Gulf Organization for Research and Development (GORD), has undertaken noticeable steps to promote and spread the adoption of sustainable construction practices in general and QSAS in particular. GORD website (gord.qa) includes a detailed description of the activities, initiatives, and programmes undertaken by the organization.

The aim of this paper is to present a framework for developing an agent-based model that can describe and forecast the diffusion of sustainable practices in the construction industry of the State of Qatar. The authors intend to use this model to evaluate the impact of a set of policy instruments and/or governmental initiatives on the adoption rate and pattern of sustainability, all on the national level. The framework can be adjusted and applied on similar cases of developing nations that are planning to transform their building sector into a sustainable one.

2. RESEARCH BACKGROUND AND OBJECTIVES

Qatar may be seen as a small country in terms of size and population; however, this sovereign state has developed immense plans for its infrastructure development, mainly relying on its hydrocarbon exports for funding (Pope 2011). As of January 2011, infrastructure and oil and gas projects estimated at USD 85 billion are under development in Qatar, with other projects of an estimated value of USD 130 billion are planned for the next three years (Pope 2011).

Examples of mega projects planned and/or are undergoing in Qatar include: a new national railway system, comprising a freight, high speed lines, light rail, and metro (estimated value = USD 25 billion); the New Doha International Airport (USD 10 billion), a new port (USD 7 billion), the Qatar - Bahrain Causeway (USD 4 billion); and the Dohaland – Musheireb urban redevelopment (USD 5.5 billion). In addition, for the 2022 FIFA World Cup that is going to be held in Qatar, 9 new state-of-the-art stadia will be constructed and three existing stadia are going to be refurbished (USD 5 billion). A set of hotel projects containing 90,000 rooms is also planned (Pope 2011).

Environmentally, the construction of the aforementioned ambitious developments will not come without a price. Given their large size, short time frame, associated extensive on-site operations as well as materials and resource use, if sustainability was not properly incorporated and applied therein their effect on the environment will be detrimental. Moreover, the State of Qatar has other concerns that force the country to go green. Qatar has scarce water resources, and in order to meet the increasing demand of water it faces many challenges including but not limited to dependence on desalinated water and limited water storage capacity (GSDP; UNDP 2009). In addition to the water paucity challenge, Qatar is facing another significant environmental challenge represented in the massive carbon dioxide emissions making Qatar, according to the World Wildlife Fund organization, on the top of the per capita carbon dioxide emission list (WWF 2010). These environmental challenges faced by the State of Qatar made the governmental decision to embrace sustainability and accelerate its adoption a must.

To that end, the authors of this paper have embarked on developing a model that can support the Qatari decision makers when considering the implementation of sustainability-related policy instruments and/or governmental initiatives. This paper presents a summary of their proposed framework for such model. The main objective of this research is to establish a new agent-based modeling approach that will (1) provide insights into the diffusion of sustainability practices in the construction industry of a developing country, and (2) provide decision makers with a tool through which they can forecast the impact of implementing certain policy instruments and/or governmental initiatives on the said diffusion. This model will help in answering the following questions:

a. What is the most appropriate modeling representation of the diffusion of sustainability?
b. What is the diffusion pattern of sustainability in the Qatari construction market under the current conditions?
c. Can a set of policy instruments lead to substantial changes in the adoption rate?
d. What are the most efficient policy instruments and/or governmental initiatives that can foster the adoption of sustainable construction practices in Qatar?

3. LITERATURE REVIEW

3.1 Diffusion Research

Diffusion is “the process by which (1) an innovation (2) is communicated through certain channels (3) over time (4) among the members of a social system”. These four elements are typically found in every diffusion research study (Rogers 2003). Nowadays, the diffusion research approach can be considered omnipresent; it has been utilized and applied in a variety of disciplinary fields including but not limited to; marketing, education, sociology, anthropology, public health, and political science.

A literature review has been carried out by the authors in order to identify the various prominent diffusion models and to capture the elements necessary for inclusion in the present sustainability diffusion research. These include the models developed by Rogers (2003), Bass (1969), Moore (1991), Fourt and Woodlock (1960), Mansfield (1961), Blackman (1974), Kalish (1985), and Kalish and Lilien (1986). Two major diffusion models of the above-mentioned are briefly described herein. It is noted that the direct application of the aforementioned diffusion models in this research may not be possible due to the special nature of the diffusion pattern of sustainability practices in comparison to typical innovations covered by such models. Also, since standard diffusion models are equation-based; these models cannot be directly applied using multi-agent systems and should be examined from a different perspective.

3.1.1 Rogers’ Model

One of the most important contributors to the field of diffusion theory is the late sociologist and communication scholar Everett Rogers whose book “Diffusion of Innovations” (Rogers 2003), has been cited in countless publications since it was first published in 1962. Under this model, any population can be categorized into 5 segments based on their tendency for adoption of a specific innovation. These segments are represented by a normally distributed curve, as shown in figure 1, and are titled as follows: innovators (2.5% of the population), early adopters (13.5%), early majority (34%), late majority (34%), and laggards (16%). It is noteworthy that each of these segments has its unique idiosyncrasies and common traits and that difference between segments are discussed by Rogers under headings such as socioeconomic characteristics, personality variables, and communication behavior (Rogers 2003).

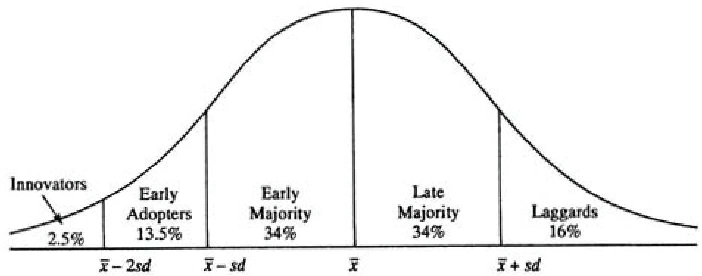

Figure 1: Adopter Categorization (Rogers 2003)

Rogers highlighted five qualities that play a vital role in the adoption of new products. These comprise (1) the relative advantage of the idea or product as compared to the one that precedes it; (2) its compatibility with existing values and practices; (3) its simplicity and ease of use; (4) its trialability, or in other words the degree to which an innovation can be experimented with on a limited basis; and (5) the product or its having observable results. Further, according to Rogers, the diffusion process encompasses four main elements namely, the innovation itself, the social system that the innovation affects, time, and the communication channels within the social system (Rogers 2003).

3.1.2 Bass' Model

The Bass model, originally developed in 1969 based on mathematical methods, assumes that potential adopters of any new innovation are mainly affected by two communication means namely, mass media and word-of-mouth. The model further assumes that there are two distinct groups of adopters; those influenced externally (i.e. through mass media), referred to as "Innovators", and those influenced internally (i.e. through word-of-mouth communication), referred to as "Imitators" (Mahajan, Muller, and Bass 1990). It is important to highlight that since its development in 1969, Bass model was subject, in more than 150 published papers, of several refinements, extensions, and applications. Numerous empirical generalizations have stemmed from the model since then as well (Mahajan, Muller, and Bass 1995).

3.2 Agent-Based Modeling and Simulation (ABMS)

Agent-based Modeling and Simulation (ABMS), the modeling technique used in this research, is a relatively new and powerful modeling approach that has been recently utilized in multiple applications, including those related to real-world business problems (Bonabeau 2002). The basic premise of ABMS is that any given system or organization must be studied as a group of interacting components and not just as the sum of its parts. Each component under the system has its own behavior and attributes, and despite the fact that some may be influential more than others, none of the components controls the behavior of the whole system on its own since each component contributes in a certain way to the results. (Macal and North 2009).The main advantages of ABMS are that it is able to show the relationship between the various components of a system, discern the ties between micro-level and macro-level behaviors, and identify conclusions that are not typically considered under a traditional line of thought. These advantages help in providing valuable insights into the system and its components which in turn allows leaders and managers to be better informed and thus make better decisions (Macal and North 2009).

3.3 ABM Diffusion Models

The literature includes recent publications from multiple disciplines where ABMS has been used in diffusion research. Garcia (2005) provides a detailed review for ABMS-based diffusion research, but his paper only covers work published up to 2005. More recent examples are listed by Rand and Rust (2011) whichinclude the work of Goldenberg, Han, Lehmann, & Hong (2009), Rahmandad & Sterman (2008), Stephen, Dover, & Goldenberg (2010), Watts (2002), Goldenberg, Libai, Moldovan, & Muller (2007), and Goldenberg, Libai & Muller (2010).

Although all of the above mentioned research studies were carried out from a marketing perspective, efforts in other fields are also present in the literature such as, to name just a few, the agricultural economics field (example: Berger 2001), water demand and consumption field (example: Galan, Lopez-Paredes and Del Olmo 2009), and the healthcare field (example: DeMarco, Kovela, Smith, Verella, Learmonth, and Patek 2009).

4. SUSTAINABILITY DIFFUSION MODEL METHODOLOGY

The discussion about the methodology for developing an ABMS-based sustainability diffusion model involves describing the data collection process, and identifying the agents and their attributes, behaviors, and interactions. The following sub-sections describe the methodology behind the model in detail.

4.1 Data Collection

4.1.1 Survey Design

Data is being collected for the model via means of a survey that includes three main parts. The first part contains thirteen multiple-choice questions that target to capture the basic information and characteristics of the surveyed companies such as: size, country of origin, Qatari experience, international experience, years in the market, and specialty. The second part comprises 25 questions based on a 5-point Likert scale with an aim of evaluating how the surveyed companies perceive sustainability, its benefits, and its status in Qatar. This part also attempts to identify the main incentives and motivations that can foster the adoption of sustainability. In developing this part, we made reference to the research carried out by Potbhare, Syal, and Korkmaz (2009) who identified various motivations and incentives for companies to adopt green building guidelines. The motivations and incentives pinpointed in the referenced research were ordered according to the results of a survey conducted by the authors in India. Although we selected some of the motivations and incentives, mentioned in the aforementioned research, as factors that can influence the adoption of sustainability, we nevertheless, opted to collect our own data from the Qatari construction industry without relying on the results of other research conducted in other regions. The third part comprises 25 questions also based on a 5-point Likert scale. These questions basically intend to assess some aspects of the organizational behavior of the surveyed companies such as the strategic preferences and risk tolerance.

4.1.2 Sampling and Data Collection

Our identified sample includes locally registered class-A contractors, international contractors working in Qatar, locally registered first class consultants (consultants licensed to undertake projects of any scale in Qatar), international consultants working in Qatar, as well as mid to large size real estate developers. The first stage of the data collection comprises conducting the survey face-to-face with company representatives. These companies are arbitrary selected and contacted, a step which is necessary for pre-testing the survey and gaining knowledge about the Qatari construction market beyond the limits of the questionnaire. The following step is publishing the survey online and circulating it among the research population for expanding the sample size.

4.2 Agents

In our sustainability diffusion model, we identified six types of agents: developer agent, consultant and project manager agent, contractor agent, policy maker agent (the government), potential market entrant - international contractor agent, and potential market entrant - international consultant agent. Table 1 below shows each agent type and its key attributes used in the development of the model. It is assumed that, because of the anticipated large magnitude of construction projects that will be offered in Qatar in the forthcoming years, no significant number of firms will be leaving the market in contrast to the potential market entrants. In the model, each type of agents is represented by a number of agents that reflects the actual presence of that type in real-life. For example, it is estimated using Zawya website (zawya.com) that, the Qatari construction market there are 24 registered developers. The model will hence include 24 developer-agents, each with a specific profile as determined by the survey described above. These developers will form project-teams with other agents representing consultants and contractors; these project-teams will serve as a medium for the diffusion of sustainability among its members.

The interactions of the agents of the model resemble those present in any typical construction sector. Developer agents tender projects and can hire consultant and contractors agents; consultant agents design and supervise projects and can influence, with varying degrees, the decisions of the developer agents; the contractor agents build projects and may also have some influence on the decisions of the developer agents but with a lesser extent; the policy maker agent introduces new rules which can affect all other agents especially the developer agents; and finally the potential market entrant agents join the model environment (Qatari construction industry) in time-steps and can work directly with developer agents.

Table 1**:** Agent Types and their Attributes

Agent Type	Key Attributes
Developer Agent	Environmentalist vs. non-environmentalist, sustainability perceptions, size of projects, contractor & consultant selection based on preferences, number of completed sustainability certified projects, strategic preferences, risk tolerance
Consultant Agent	Environmentalist vs. non-environmentalist, sustainability perceptions, size of projects, experience in Qatar & internationally, number of LEED and QSAS certified professionals, influence on developer agents, number of completed sustainability certified projects, strategic preferences, risk tolerance, flexibility to adopt changes, and QA/QC system.
Contractor Agent	Environmentalist vs. non-environmentalist, sustainability perceptions, size of projects, experience in Qatar & internationally, number of LEED and QSAS certified professionals, influence on developer agents, number of completed sustainability certified projects, strategic preferences, risk tolerance, flexibility to adopt changes, and QA/QC system.
New Market Entrant – Int. Consultant Agent	Exogenous agents (transforms to consultant agents based on a specified time step), environmentalists vs. non-environmentalist
New Market Entrant – Int. Contractor Agent	Exogenous agents (transforms to contractors agents based on a specified time step), environmentalists vs. non-environmentalist
Government Agent (Policy Maker)	Exogenous agent

Initially, agents will be either considered non-adopters, potential adopters, or actual adopters of sustainability according to their environmental awareness. Using the results of the survey, this will be further followed by an analysis aimed at dividing the entire population of the model into 5 categories (innovators, early adopters, early majority, late majority, and laggards) according to Rogers' model, described in section 3.1 above, for a more detailed view of the adoption status.

4.3 Model Framework and Agents Interactions

As mentioned above, the proposed model will simulate the typical interactions between developers, consultants, contractors, and the policy maker (government). It will also allow for new international firms to progressively join the market at sequential time steps to reflect the actual dynamics in the Qatari construction sector. In the model, each developer, consultant, and contractor agent represents a firm whose adoption decision depends, inter alia, on a set of motivations, and incentives. A graphical representation of the model is shown in Figure 2 below. Theoretically, the decision to adopt sustainability by an agent can be reached through one of two routes: (1) interacting with other agents (i.e. by participating in a specified number of sustainable projects), or (2) through taking an independent decision to adopt sustainability based on the perceived utility without the need for having the necessary interactions with other adopting agents.

Each agent will be programmed to have an attitude towards adoption. This attitude will reflect its behavioral intentions on a scale from 1 to 5, similar to the likert scale provided in the survey we are conducting. It will also specify the utility that each agent perceives regarding the decision to adopt sustainability. When running the model, at every time-step when each agent will interact, according to its characteristics and with an assigned probability, with other randomly selected agents to create a project team and thus receives information from them. Such information may result in an increase in the agent's attitude towards adoption leading the agent to take the decision to adopt sustainability and become an actual adopter.

In order to model other indirect parameters that can influence an agent's decision to adopt sustainability such as market pressure, we will incorporate the threshold model of collective behavior (Granovetter, 1978) in our model. In such adoption cases, no direct interaction between an agent and any other agents is necessary for an adoption decision to be taken. The basic premise of Granovetter's model (1978) is that an individual can take the decision to engage in a behavior or adopt a technology based on the proportion of others in the system who have already taken that decision and are engaged in that behavior. Accordingly, the decision to adopt by an individual can be represented as a function of the behavior of other individuals in the system. Those who take the adoption decision first are those with low thresholds compared to others who wait till the majority of those in the system take such decision. For the implementation of this theory in our model, each agent will be programmed to check, at time steps, the model's overall adoption level and compare it with its own threshold. If the threshold is met, and after checking against other parameters such as its knowledge about sustainability and its risk tolerance, a decision to adopt sustainability may be taken by the agent.

4.3.1 Base Case and Policy Incentives

The initial design and run of the model will be centered on a base case representing the status quo of the Qatari construction industry as determined by the survey. The base case will reflect as practically possible the current awareness, attitude, incentives, motivations, and governmental level of sustainability endorsement. After the first run, the policy maker agent will start providing pre-established incentives to other agents, specifically developers, to turn them into adopters. Incentives will include for example, special regulations, financial allowances and funding, reduced governmental fees, additional allowable building area, and undertaking promotional activities to increase the awareness of sustainability.

In this scenario evaluation component of the model, each agent will have an attitude towards every incentive offered by the policy maker agent; the attitude will be interpreted from the results of the survey. As explained earlier in this section of the paper, the model will simulate the policy incentives scenario within each time step and determine the corresponding adoption level that will change in response to the applied incentives.

5. MODEL IMPLEMENTATION

For the implementation of the model and the creation of its agent-based simulations, we intend to use the last version of Repast (REcursive Porous Agent Simulation Toolkit) toolkit namely, Repast Simphony 2.0 (Repast S) released on the fifth of March 2012. Repast, which has been widely used in many domains such as social simulation applications, is considered as a leading free and open source ABMS toolkit (Macal and North 2005).

Compared to other toolkits, Repast S has several advantages that led it its popularity. One of these advantages is the graphical user interface (GUI) that allows users of the toolkit to design the model, its components, and its logic and spatial structure visually via graphical point-and-click tools (Macal and North 2009). Repast S interface also allows for controlling the execution of the simulations by introducing control functionalities like pausing, stepping and stopping. Repast S runtime environment provides the opportunity for the analysis of the results and connections to a range of spreadsheet, visualization, data mining, and statistical analysis tools (Macal and North 2009).

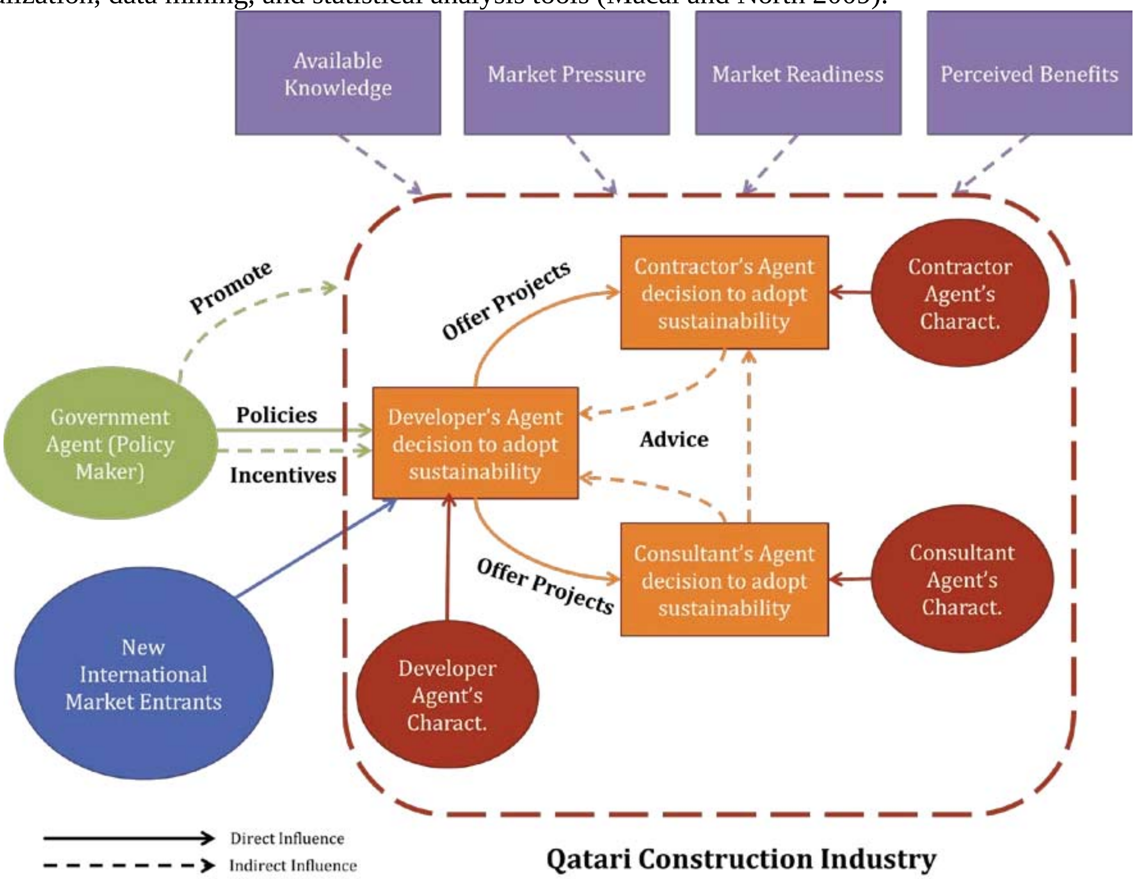

Figure 2: Sustainability Diffusion Model Conceptual Framework

6. CONCLUSIONS AND LIMITATIONS

Sustainable construction is entering the mainstream in many of the developed countries and some developing countries are taking solemn measures to embrace it. This paper presents an agent-based proposed framework for a model that can be used to determine, and further, forecast the adoption level of sustainability in any given construction sector. A scenario evaluation component can be also added to the model in order to estimate the level of increased adoption that can result from a specified set of policy instruments. A description of the agents and their tentative attributes, behaviors, and interactions is provided herein. Although the framework is mainly based on the Qatari construction sector, only minor elements- such as the role of the government in the industry and the potential entrance of international entities- will require adjustment in order for the model to be tailored to any other case regardless of the level of adoption.

The main limitation of the model is its reliance on a survey to determine the industry's level of sustainability awareness and the firms' attitude towards sustainability and any potential policy instruments as well. Despite the fact that we only targeted senior professionals working within the firms selected for interviews, the responses provided in the survey may be only a reflection of the personal perceptions of the interviewee and not of the organization as an entity. Similarly, the attitude of the agents towards the policy instruments will not be based on a cost-benefit analysis and may be also reflecting personal perceptions. This limitation is planned to be subject to further research that will aim at developing and incorporating a cost-benefit analysis model that influences the attitude of agents towards sustainability given their profiles.

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