# Sustainability Adoption in Growing Construction Markets: an Agent- based Diffusion Model

Mohamed E. Hassan[1],
[1] Ph D Candidate,
School of Civil Engineering,
Purdue University,
Indiana, USA

Sherif Attallah[2],
[2]Assistant Professor,
School of Applied Science and Technology,
Ball State University,
Indiana, USA

Amr Kandil[3]
[3] Associate Professor,
School of Civil Engineering,
Purdue University,
Indiana, USA

*Abstract* - **Over the past two decades, many governments around the world have taken notice of the detrimental impact of the construction industry on the environment and have initiated plans to promote sustainable construction practices. These plans range from offering incentives that motivate construction firms to adopt sustainability up to imposing penalties on non-conforming firms that develop projects that pollute the environment. This paper presents a research study that targets to provide an insight on the impact of different governmental policies on the adoption levels of sustainability by construction developers in an emerging construction market, specifically the Qatari construction sector. This insight is achieved through the development of an agent-based model loosely based on the diffusion models of Rogers and Bass, which describe the adoption process of new products in a population formed of units of adoption. Our model showed that using agent-based modelling and prominent diffusion models can be helpful in understanding how construction firms would react to different governmental policies that target to increase the adoption of sustainable construction practices.**

***Key Words: Sustainability, Sustainable Construction, Diffusion, Diffusion Modelling, Roger Model, Bass Model***

## 1. INTRODUCTION

Construction projects are typically associated with the use of significant amounts of energy and materials, the emission of considerable amounts of greenhouse gases, and the generation of tons of waste. This is exacerbated by the fact that some of these detrimental impacts on the environment extend throughout the life cycle of projects mainly due to poor design and/or operation decisions. Thus, for decades, the construction industry has been notorious as a main contributor to the depletion of natural resources and environmental deterioration. In the United States for example, the construction sector consumed, as of the year 2001, around forty percent of the materials extracted annually in addition to thirty percent of all primary energy. It also generated wastes in excess of 145 million metric tons amounting to one-third of landfilled materials per year [1]. Moreover, the building sector is responsible globally for the emission of around forty percent of greenhouse gases leading to environmental degradation in the form of pollution and global warming [2]. In the Organization for Economic Cooperation and Development (OECD) countries, which currently include 34 developed and semi-developed countries, the building sector consumes between 25 to 40 percent of the total energy consumption [3]. On the other hand, the situation in developing countries is even more serious given the public health issues that result in consequence of the detrimental impacts of the construction industry on the environment, especially in urban areas [4].

Due to the major indispensable role that the construction industry plays in development and with the upsurge of environmental awareness, many nations around the world undertook notable efforts in order to promote sustainability in general and sustainable construction in particular. In this regard, the concept of sustainable construction encompasses the life cycle of a project beginning from the planning and early design stages up to the end-of-life fate of the materials used therein; including construction, operation and retrofitting stages as well [1]. Therefore, some entities, governmental and non-governmental, have established unique green building guidelines and rating systems in order to regulate and guide sustainable construction practices adoption. Chief examples of prominent rating systems that have proliferated beyond their countries of origin and were adopted in multiple regions worldwide include LEED, BREEAM, and CAASBEE developed by U.S. Green Building Council (USGBC), Building Research Establishment (BRE), and Japan Sustainable Building Consortium (JSBC) respectively.

The government of the State of Qatar, the country which the case study presented here is based upon, is one of the governments that have recently shown considerable interest in promoting sustainability and considered it as one of the Pillars of Qatar National Vision 2030. In fact, this issue is of paramount importance to Qatar considering the scarcity of its natural resources and the deteriorating status of the environment, which led the World Wildlife Fund (WWF) organization, to place Qatar, as of the year 2010, on top of the per capita carbon dioxide emission list [5]. Qatar's recent attention to the status of the environment has been demonstrated by the development and deployment of Qatar Sustainability Assessment System (QSAS), which resembles some aspects of the aforementioned LEED system, but was designed to respond to the country's specific environmental and local needs. Since QSAS deployment in 2009, Qatar has embarked on evident steps with the aim of promoting and increasing the adoption of sustainability in general and QSAS in particular. This might require the Qatari government to consider applying a number of policies that can support its direction in wide spreading the adoption of sustainable construction. To that end, this paper presents an agent-based model that can provide an insight on the impact of different governmental policies on the adoption of sustainability by construction developers with the aim of identifying the most effective policy that would lead to a higher level of adoption. The model is inspired by and is loosely based on the prominent diffusion models developed by Everett Rogers and Frank Bass in the 1960s. Even though the model we propose and the results we achieved are all based on the Qatari construction industry and the developers, consultants, and contractors operating therein, the concept of the model can be directly applied on other developing nations that intend to transform their construction sector into a sustainable one.

## 2. BACKGROUND

Diffusion can be defined as the process through which "an innovation is communicated through certain channels over time among the members of a social system" [6]. The said diffusion process has been thoroughly investigated over the years since the concept became popular in the 1960s and the literature pertaining to various disciplines including, but not limited to, sociology, marketing, education, political science, and public health demonstrate the ubiquitousness of the subject. Among the leading scholars who made the most significant contribution to the diffusion theory are Everett Rogers and Frank Bass who first published their models in 1962 and 1969 respectively. The following paragraphs of this section briefly introduce the models of Rogers and Bass which inspired our model presented in this paper.

### *Rogers' Diffusion of Innovations Model*

The chief contribution of Everett Rogers to the diffusion theory is perhaps best embodied in his highly cited book "Diffusion of Innovations", first published in the year 1962 and now in its fifth edition [6]. In his book, Rogers analyzed several aspects of the diffusion process such as the elements of diffusion and the process of the innovation-decision. Rogers also described the different attributes of innovation and rate of adoption and further categorized the adopters of a particular innovation based on a set of characteristics.

The elements of diffusion, according to Rogers, encompass the four elements identified in his definition of the term "diffusion" provided above. These include the innovation itself, the channels of communication, time, and the social system. The innovation does not necessarily have to be new; however, it should be an idea, practice, or project that is "perceived" as new by the individuals (or the units of adoption). The second element of the diffusion process is the channels of communication through which the individuals share information and send messages about the innovation such as mass media and interpersonal channels. The third element is time that adds the time dimension to the different aspects of the diffusion process, such as for instance, the rate of adoption and the innovation-decision process. The final element is the social system which is defined by Rogers as the "set of interrelated units engaged in join problem solving to accomplish a common goal" [6]. The social system represents the boundary within which that innovation can spread and diffuse.

In Rogers' model, the individuals within a social system can be categorized based on their tendency to adopt an innovation (referred to as innovativeness) into five segments represented by a normally distributed curve. These five segments are: (1) innovators (representing 2.5% of the population); (2) early adopters (13.5%); (3) early majority (34%); (4) late majority (34%); and (5) laggards (16%). The reader is kindly advised to refer to Chapter 7 of Rogers' book "Diffusion of Innovations" for the detailed characteristics of the individuals under each of the aforementioned segments (Rogers 2003). Moreover, Rogers identified five qualities that play a vital role in the adoption of innovations. 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 trial-ability, or in other words, the degree to which an innovation can be experimented with on a limited basis; and (5) the product having observable results. Rogers' model has been heavily used in studying the diffusion of numerous products and innovations in different contexts such as technology and education. However, it is important to highlight that the model has also been challenged by several researchers especially regarding its assumption of a linear trajectory that starts from invention, to the specification of requirements according to user needs, up to market commercialization. These arguments can be found in the works of Dosi [7] and Baskerville and Pries_Heje [8]. Finally, an expansion to Rogers' model was further suggested by Rogers himself who proposed augmenting the diffusion model concept with complex adaptive systems (CAS) models to allow capturing emergent behaviors that might be produced during the adoption process [9].

### *Bass Model*

In contrast to Rogers' qualitative approach, Frank Bass diffusion model, first developed in 1969, is based on mathematical methods that utilize differential equations to forecast consumer behavior towards innovations. Bass considers that any potential adopter of an innovation is going to be affected by either of mass media or word-of-mouth as the two main communication means [10]. The model divides the adopters into two categories: (1) The Innovators group, which is the group of adopters that are only influenced externally through mass media; and (2) The Imitators group, which is influenced internally through word-of-mouth only.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 08, August-2016

Since it was published, the Bass model became highly popular within the marketing and consumer behavior fields sparking a dedicated field of research that primarily focuses on empirical diffusion models. This has led to the further development of numerous revised forms to the model, some in collaboration with Bass himself, comprising different refinements, extensions, and/or modifications to the original model's structure and conceptual assumptions [11]. Among the many extensions and modifications introduced to the generalized form of Bass model, Norton and Bass [12], for example, proposed a revised form that considers successive generations of an innovation allowing the estimation of diffusion parameters of future generations using early generations data. Wilson and Norton [13] then studied the optimal introduction timing in the case of such innovations (or products) that have successive generations. Focusing mainly on the communication structure within the Bass model, Tanny and Derzko [14] developed an extension that involves considering potential innovators and imitators to be both affected by mass media whereas potential imitators only to be the ones affected by word-of-mouth. Moreover, Kamakura and Ealasubramanian [15] and Jain and Rao [16] studied the impact of price on the rate of diffusion and adoption while other researchers focused on the impact of negative word-of-mouth [17]. Other extensions and modifications include the works of Horsky and Simon [18] and Simon and Sebastian [19] who investigated the impact of advertising on diffusion.

## 3. METHODOLOGY

As mentioned above, Rogers described an innovation as an "idea, practice, or project perceived as new by an individual or other unit of adoption" [6]. Based on that description, one can view sustainable construction as a relatively new practice, and hence, as an innovation, that has recently gained considerable traction and attention in many countries around the globe. For our research and modeling purposes, we limited the definition of sustainable construction projects to projects that have achieved a sustainability certificate (i.e. LEED, QSAS, or BREEAM). Accordingly, the diffusion of sustainable construction referred to throughout this paper can be equated with the diffusion of green building guidelines described in details by Potbhare et al. [20]. Similar to any innovation, for sustainable construction to diffuse, information regarding its practices must be communicated within the construction industry. Such communication typically happens through multiple channels such as academic and technical journals and magazines, bulletins, media campaigns, conferences and seminars, as well as through policies issued by governments.

The main objective of our research is to study the diffusion of sustainable construction as an "innovation" and identify policies that can foster its adoption. In achieving this target, we focused on the construction industry of the State of Qatar as a case study and therefore, our data and results are essentially based on that market; nevertheless, the methodology itself can be applied on the construction industry of any other country regardless of its size and current level of adoption. This section of the paper describes the sequential steps we followed in developing our agent-based sustainability diffusion model inspired by the models of Rogers and Bass.

*Step 1: Developing the Model Structure*

As an agent-based model, the heart of our model is the agents that represent the units of adoption. These agents are confined within the boundary of a social system, which is the Qatari construction industry in this case study. Here, we chose the projects' developers (also known as owners or clients) that are actively operating within the construction industry of Qatar to be the units of adoption in the diffusion model. The reason is that the decision on whether a construction project is going to achieve a sustainability certification (e.g. LEED certification) is almost universally taken by the owner of the project. Our model includes 25 developer agents which is a number commensurate with the actual number of active Qatari construction developers according to a list acquired from Reuters-owned business intelligence website "Zawya.com" in the year 2012 [21].

In their initial status before running the model, all developer agents are considered to be non-adopters. After every cycle of the model, each developer agent can be either a non-adopter of sustainable construction or in one of two states of adoption, partial adoption or full adoption. We define partial adoption as a state in which the developer is well informed about sustainable construction and applies it in some of its projects whereas full adoption is a state in which the developer is a firm believer in sustainable construction and enforces it in all its projects. This classification might be viewed as a resemblance to the categorization in the generalized Bass model, which also divides adopters into two categories: adopters to imitators and imitators. However, we must note that Bass categorization is based on the characteristics of the adopters whilst the categorization presented here is based on the level of adoption of the developer agents who are further allowed to make a transition from one state of adoption to another. This transition happens depending on the susceptibility of each agent to external factors determined according to each agent's own attributes and behavior. It is important to highlight that the attributes and behavior of agents can either increase an agent's interest in sustainable construction or reduce it, which is a significant departure from classical diffusion models that do not allow for such emergent behavior to happen.

*Step 2: Identification of parameters*

Typically, project developers in real life do not interact directly with one another for the purpose of adopting sustainability. Hence, each developer agent in our model was also designed not to directly interact with other developers in order to mirror that aspect. Instead, agents were designed to interact only with the entire social system as a whole through being subject to different diffusion parameters and policies. This can then lead to a higher/lower state of adoption according to the impact of these parameters and policies on each agent. Therefore, after establishing the structure of the agent-based sustainability diffusion model, the following step was to identify the said diffusion parameters and policies that will be imposed by the social system on each agent individually. Due to the special nature of the innovation being studied here, we opted not to directly apply the parameters identified by Bass (i.e. word-of-mouth, and mass media) and to introduce, alternatively, more specific ones tailored to the diffusion of sustainable construction.

To identify the diffusion parameters, their effectiveness and impact on the agents' adoption level, and to have a thorough understanding of the Qatari construction industry and its constituents in general, we designed a survey that was then administered to construction firms operating in Qatar. The survey comprised three sections, each having a different scope. The first section targeted to capture the basic information about the surveyed companies such as their specialty in the market, years in business, size, country of origin, international experience, and Qatari experience. The second section aimed at evaluating how the surveyed companies perceive sustainability, its benefits, and its status in Qatar. It also allowed determining the views of the surveyed firms on the potential impact of governmental policies that would target to increase the adoption of sustainability. In developing this section of the survey, we made reference to the research carried out by Potbhare et al. [19] who pinpointed and ordered various incentives and motivations that can influence firms to adopt green building guidelines. Finally, the last section was designed to assess several aspects of the organizational behavior of the surveyed companies such as their risk tolerance and strategic preferences to have an understanding of the behavioral attributes of the firms in the market as represented by the surveyed companies.

The administration of the survey was initiated by sending meeting requests to 92 developers, contractors, and consultants actively operating in the Qatari construction industry, 25 of which accepted the request. This indicated a response rate of around 27%. Individual meetings were then arranged with a senior representative of each of the firms that accepted the request to go through the survey. Despite the relatively low number of the sampling units (25 firms), we consider this number sufficient for our modeling purposes considering the small size of the construction industry in Qatar and the few number of firms operating there; estimated by the authors using local data at around 200 firms. We also believe that by only interviewing and meeting with senior representatives of the surveyed firms a higher credibility in the survey results was achieved.

Using the survey results, we identified key parameters that can be considered to influence the adoption (or rejection) of sustainable construction the most. In addition, five potential policies, plus two combination of policies, that the survey respondents believe to potentially have the highest impact on the diffusion were also identified. The parameters that were found to have a high impact on developers' adoption of sustainable construction include the influence of consultants on developers to achieve a sustainability rating as well as the perceived benefits of sustainable construction by developers such as enhancing their reputation in the market. On the other hand, parameters that were found to discourage developers to fully adopt sustainable construction in Qatar comprise the extra cost of achieving a sustainability rating in a project and the lack of market readiness for full-fledged adoption due to multiple reasons including, inter alia, the difficulty in acquiring local and recycled materials in Qatar. The five scenarios that we evaluated using the survey covered increasing the prices of water and energy by the government since they are currently heavily subsidized, offering financial incentives such as tax cuts to developers constructing sustainable projects, arranging dedicated media campaigns to increase awareness, in addition to imposing financial penalties on non-sustainable projects.

Table 1 – Sustainability Diffusion Parameters Description

| Parameter | Description |
|---|---|
| Consultants Influence | Positive influence of consultants with sustainability experience on the adoption decision by developers/owners. |
| Perceived Benefits | Potential impact of the benefits that developers believe they will achieve by adopting sustainability on the diffusion such as competitiveness in the market and enhanced reputation. |
| Extra cost of sustainability | Potential effect of the extra cost that developers believe they will incur as a result of adopting sustainability. |
| Un-readiness of Construction Market | Full adoption of sustainability in Qatar is considered to be challenging in the time being considering, inter alia, the difficulty in obtaining local and recycled materials. This parameter only influences the transition from partial adoption state to full adoption in reflection to that fact. |
| Policy 1 - Water Price Increase | Potential impact of a governmental policy leading to an increase in water price, which is currently heavily subsidized by the Qatari government. |
| Policy 2 - Energy Price Increase | Potential impact of a governmental policy leading to an increase in energy price, which is currently heavily subsidized by the Qatari government. |
| Policy 3 - Financial Incentives by Government | Potential impact of a governmental policy involving offering financial incentives such as tax cuts to firms adopting sustainable construction. |
| Policy 4 - Dedicated Media Campaigns | Potential impact of dedicated media campaigns highlighting the benefits of sustainable construction aiming to promote its adoption. |
| Policy 5 - Imposing Penalties on Non-sustainable Projects | Potential impact of a governmental policy involving applying penalties on developers of non-sustainable construction projects. |
| Policy 6 - Water and Energy Prices Increase | Potential impact of applying both Policy 1 and Policy 2 concurrently. |
| Policy 7 Water and Energy Prices Increase + Financial Incentives by Government | Potential impact of applying all of Policy 1, Policy 2, and Policy 3 concurrently. |

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 08, August-2016

Table 1 provides a description of all identified parameters and policies and table 2 presents the values of these parameters calculated through averaging and processing the survey results. Each value associated with a parameter defines the percentage of developers that will be affected by that parameter during each cycle in the model, chosen to be 1 year. The aggregation of the effect of all parameters and policies on an agent triggers a transition, if any, in the state of that agent (e.g. from non-adopter to partial adopter or vice versa). In other words, the state of each agent after every cycle is determined stochastically by the model based on the aggregate impact of all parameters and policies on the agent considering its current state.
As shown in table 2, the values of the parameters may differ depending on the adoption state the agent is transitioning to. This is due to the fact that transitioning from a non-adoption state to a partial adoption one was considered to be significantly more likely under specific policies compared to transitioning from partial adoption to full adoption.

Table 2 – Sustainability Diffusion Parameters

| Parameter | Value (Non-adopters to Partial Adopters) | Value (Partial Adopters to Full Adopters) |
|---|---|---|
| Consultants Influence | 0.08 | 0.08 |
| Perceived Benefits | 0.88 | 0.20 |
| Extra cost of sustainability | -0.12 | -0.12 |
| Un-readiness of Construction Market | N/A | -0.32 |
| Policy 1 - Water Price Increase | 0.36 | 0.04 |
| Policy 2 - Energy Price Increase | 0.44 | 0.16 |
| Policy 3 - Financial Incentives by Government | 0.80 | 0.12 |
| Policy 4 - Dedicated Media Campaigns | 0.72 | 0.12 |
| Policy 5 - Imposing Penalties on Non-sustainable Projects) | 0.56 | 0.28 |

*Stage 3: Implementing the Model*

The final stage in developing the agent-based sustainability diffusion model was the implementation and results production stage. We used the simulation modeling tool AnyLogic 6 to create the agents and run the agent-based model. At first, the base case was implemented without adding any of the identified policy scenarios and then, each policy was added to the model and run independently as a separate case. Figure 1 shows eight sub-figures providing the output of the model over a period of 10 years under the base case and the different policy scenarios where the bottom, middle, and top parts of each sub-figure represent the number of non-adopters, partial adopters, and full adopters respectively out of a total of 25 agents.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 08, August-2016

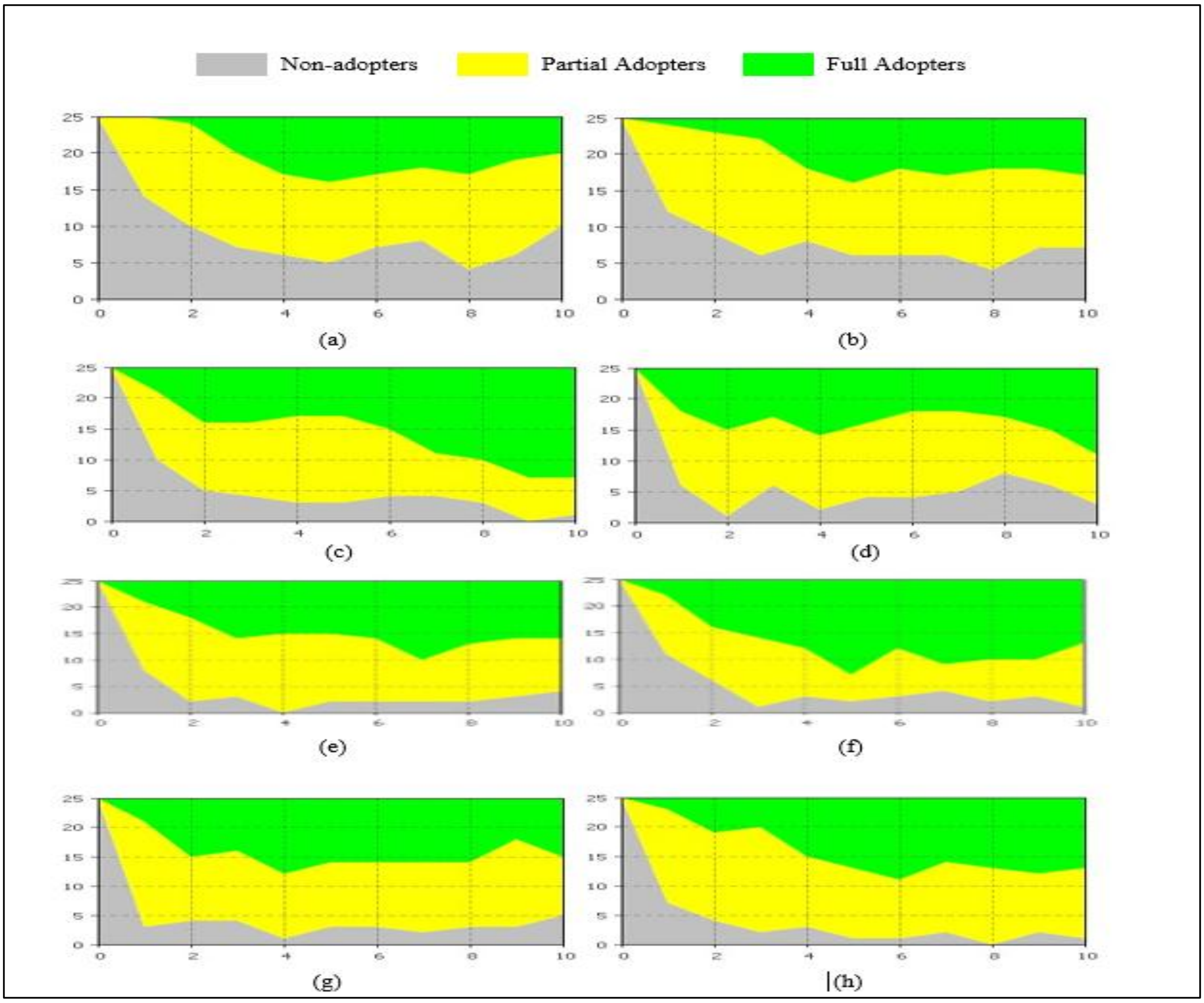


Figure 1 – (a) Base case; (b) Policy 1 (Water Price Increase); (c) Policy 2 (Energy Price Increase); (d) Policy 3 (Financial Incentives by Government); (e) Policy 4 (Dedicated Media Campaigns); (f) Policy 5 (Imposing Penalties on Non-sustainable Projects); (g) Policy 6 (Water and Energy Prices Increase); (h) Policy 7 (Water and Energy Prices Increase + Financial Incentives by Government)

## 4. RESULTS AND DISCUSSION

Tables 3, 4, and 5 present the estimated percentage of developers that are non-adopters, partial adopters, and full adopters of sustainable construction over the short-term (2 years), medium-term (5-years), and long-term (10-years). These results indicate that, under the current conditions in Qatar, it is highly unlikely that sustainable construction will be fully adopted by a substantial portion of developers without enforcing policies that push developers towards making that transition. As shown in the tables, over the medium-term, the full adoption of sustainable construction seems to be in its peek; nevertheless, several developers are expected to fall back to the partial adoption state as a result of the challenges they will face in conforming to sustainability requirements in terms of types of materials and recycling in addition to the extra cost typically incurred in achieving a high sustainability rating. It is also noted that the perceived benefits of adopting sustainability appears to decrease considerably for developers to make a transition from partial adoption to full adoption leading to that result.

Table 6 – Level of Adoption after 2 years

| Level of Adoption | Base Case | Policy 1 | Policy 2 | Policy 3 |
|---|---|---|---|---|
| Non-Adopters | 40% | 32% | 20% | 8% |
| Partial Adopters | 56% | 60% | 44% | 52% |
| Full Adopters | 04% | 08% | 36% | 40% |
| | Policy 4 | Policy 5 | Policy 6 | Policy 7 |
| Non-Adopters | 12% | 24% | 16% | 16% |
| Partial Adopters | 60% | 40% | 44% | 60% |
| Full Adopters | 28% | 36% | 40% | 24% |

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 08, August-2016

Table 4 - Level of Adoption after 5 years

| Level of Adoption | Base Case | Policy 1 | Policy 2 | Policy 3 |
|---|---|---|---|---|
| Non-Adopters | 20% | 24% | 12% | 16% |
| Partial Adopters | 44% | 40% | 56% | 48% |
| Full Adopters | 36% | 36% | 32% | 36% |
| | Policy 4 | Policy 5 | Policy 6 | Policy 7 |
| Non-Adopters | 8% | 8% | 12% | 4% |
| Partial Adopters | 52% | 24% | 44% | 48% |
| Full Adopters | 40% | 68% | 44% | 48% |

Table 5 - Level of Adoption after 10 years

| Level of Adoption | Base Case | Policy 1 | Policy 2 | Policy 3 |
|---|---|---|---|---|
| Non-Adopters | 40% | 28% | 4% | 12% |
| Partial Adopters | 40% | 40% | 24% | 36% |
| Full Adopters | 20% | 32% | 72% | 52% |
| | Policy 4 | Policy 5 | Policy 6 | Policy 7 |
| Non-Adopters | 16% | 4% | 20% | 4% |
| Partial Adopters | 40% | 48% | 40% | 48% |
| Full Adopters | 44% | 48% | 40% | 48% |

Should the Qatari government target to increase the adoption of sustainable construction beyond the low figures achieved without any governmental intervention, there are a number of policies that seem to be effective in this regard. To that end, an increase in the price of energy in Qatar, which is currently highly subsidized, shows to provide the highest percentage of partial adopters over the medium term and the same for the percentage of full adopters over the long term of 10 years. This highlights the importance of the price of energy to construction developers especially that most of them in Qatar are focused on the real-estate business, which is directly affected by energy prices during both the construction and operation phases of projects.

One surprising result of the model is that the policy that achieved the highest percentage of full adoption of sustainability over the medium-term is the arrangement of media campaigns dedicated to promote sustainability in general and sustainable construction in particular. This highlights the fact that the surveyed companies believe that there is a general lack of awareness about sustainable construction in the Qatari construction industry that might be contributing to the current non-adoption state of some developers. Nevertheless, our results also indicate that the percentage of full adopters might decrease markedly over the long-term under that policy demonstrating that media campaigns on their own are not sufficient to sustain the growth in the number of full-adopters without any real incentives and/or imposed penalties. Another policy that seem to be potentially effective in the Qatari market would be to impose penalties on non-sustainable construction projects. This policy is estimated to result in a considerably lower percentage of non-adopters over the long-term. Under this policy, developers will likely be more inclined to adopt sustainable construction not only to avoid incurring monetary damages, but also in concern for the reputation of their projects and firms in the market if news about the application of penalties were to be made public.

We attempted to combine different policies in individual runs of the model such as policy 6 (a combination of policies 1 and 2), and Policy 7 (a combination of policies 1, 2, and 3); however, we found out that this did not result in a noticeable increase in the percentage of adopters of sustainable construction according to our model. This shows that, after a certain level of adoption, the impact of policies will diminish and some developers will still steer away from adoption due to the challenges inherent with adopting sustainability and the extra cost incurred in developing sustainable projects.

## 5. CONCLUSION

In this paper, a novel approach is presented to study the diffusion of sustainability within a small and emerging construction market as well as the potential impact of different governmental policies on that diffusion. The approach utilizes agent-based modeling and is loosely based on the prominent diffusion models established by Everett Rogers and Frank Bass. We focused on the Qatari construction industry as a case study and therefore the data used in developing the model was collected only from there; nevertheless, the same approach can be applied elsewhere using relevant data.

The results of our model showed that under the current conditions in Qatar, it is unlikely that sustainable construction will achieve a wide-spread adoption among Qatari developers. However, there are some policies that appear to have the potential to make a noticeable impact on the percentage of adopters such as increasing energy prices and imposing penalties on non-sustainable projects. Our research also indicates that one of the main obstacles in achieving high level of full adoption is the lack of readiness in the Qatari construction industry as highlighted by the scarcity of local construction materials and the lack of recycling facilities. This appears to be continuing to hinder the full-fledged adoption of sustainable construction by developers. We believe that the alleviation of these hurdles by the government will play a key role in increasing the number of developers embracing sustainable construction, which will in turn reflect on the state of the environment in Qatar.

Finally, we need to emphasize that our approach is not intended to provide an accurate forecast of the percentage of adopters under different policies. Similar to other agent-based models, the results of the model are intended to be taken as indicative considering that such ABM models typically shift towards the descriptiveness end in the tradeoff between the tractability of the analysis and representational accuracy [22]. The key benefit of the approach is that it provides an insight on the factors influencing the diffusion of sustainable construction in an emerging market and the impact of one policy relative to the other policies on that diffusion.

ACHKNOWLEDGEMENT

The authors wish to acknowledge Qatar National Research Foundation (NPRP No.: 09-717-2-274) for providing funds for this research study. All the opinions and views in this study are solely that of the authors, and do not reflect the opinions of QNRF.

REFERENCES:

[1] Kibert, C. J. (2001). "Policy Instruments for Sustainable Built Environment." J. Land Use & Envtl. L., 17, 379-394.
[2] United Nations Environmental Programme (UNEP) (2003). "Sustainable building and construction: facts and figures."
[3] Organisation for Economic Development and Cooperation (OECD) (2003). Environmentally sustainable buildings: challenges and policies, OECD Publishing.
[4] Melchert, L. (2007). "The Dutch sustainable building policy: A model for developing countries?" Building and Environment, 42(2), 893-901.
[5] World Wildlife Fund Organization (WWF) (2010). "Living Planet Report."
[6] Rogers, E. M. (2003). Diffusion of innovations, Simon and Schuster, New York, NY 10020.
[7] Dosi, G. (1982). "Technological paradigms and technological trajectories: a suggested interpretation of the determinants and directions of technical change." Research policy, 11(3), 147-162.
[8] Baskerville, R., and Pries_Heje, J. (2001). "A multiple _theory analysis of a diffusion of information technology case." Information Systems Journal, 11(3), 181-212.
[9] Rogers, E. M., Medina, U. E., Rivera, M. A., and Wiley, C. J. (2005). "Complex adaptive systems and the diffusion of innovations." The Innovation Journal: The Public Sector Innovation Journal, 10(3), 1-26.
[10] Bass, F. M. (1969). "A New Product Growth For Model Consumer Durables." Management Science, 15(1), 215.
[11] Mahajan, V., Muller, E., and Bass, F. M. (1990). "New product diffusion models in marketing: A review and directions for research." The Journal of Marketing, 1-26.
[12] Norton, J. A., and Bass, F. M. (1987). "A diffusion theory model of adoption and substitution for successive generations of high-technology products." Management science, 33(9), 10691086.
[13] Wilson, L. O., and Norton, J. A. (1989). "Optimal entry timing for a product line extension." Marketing Science, 8(1), 1-17.
[14] Tanny, S. M., and Derzko, N. A. (1988). "Innovators and imitators in innovation diffusion modelling." Journal of Forecasting, 7(4), 225-234.
[15] Kamakura, W. A., and Ealasubramanian, S. K. (1987). "Long_term forecasting with innovation diffusion models: The impact of replacement purchases." Journal of forecasting, 6(1), 1-19.
[16] Jain, D. C., and Rao, R. C. (1990). "Effect of price on the demand for durables: Modeling, estimation, and findings." Journal of Business & Economic Statistics, 8(2), 163-170.
[17] Mahajan, V., Muller, E., and Bass, F. M. (1995). "Diffusion of new products: Empirical generalizations and managerial uses." Marketing Science, 14(3 supplement), G79-G88.
[18] Horsky, D., and Simon, L. S. (1983). "Advertising and the diffusion of new products." Marketing Science, 2(1), 1-17.
[19] Simon, H., and Sebastian, K.-H. (1987). "Diffusion and advertising: the German telephone campaign." Management Science, 33(4), 451-466.
[20] Potbhare, V., Syal, M., and Korkmaz, S. (2009). "Adoption of green building guidelines in developing countries based on US and India experiences." Journal of Green Building, 4(2), 158-174.
[21] Zawya website, http://www.zawaya.com, (18 April 2012).
[22] Galán, J. M., López_Paredes, A., and Del Olmo, R. (2009). "An agent _based model for domestic water management in Valladolid metropolitan area." Water Resources Research, 45(5).