The Role of Building Information Modeling (BIM) in the implementation of Rainwater Harvesting Technologies and Strategies (RwHTS)

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ABSTRACT

Sustainable innovations are observed as a major way by which the ill-effects of the built environment can be avoided or offset. The adoption of innovations are critical to the society, as they pave the way for further incremental or radical innovations, depending on the feedback from their users. In this process, the attributes of an innovation play an important role in its adoption. The objective of this study was to determine whether observability, one of many attributes of innovations identified in the literature as affecting their adoption, plays a critical role in the adoption of sustainable innovations, specifically Rainwater Harvesting Technologies and Strategies (RwHTS). Further, the study aimed to determine whether the use of Building Information Modeling (BIM) resulted in frequent adoption RwHTS. Last but not least, the study also sought to understand how designers used BIM to enhance the acceptance of RwHTS in capital projects. The stakeholders identified for this study were architectural firms that are geographically located in the southeastern states of the United States, and the study was conducted from their perspective. This study was segregated into two major phases. The first phase involved a survey of 2,200 designers/architects located in seven southeastern states, including Georgia, North Carolina, South Carolina, Florida, Virginia, Maryland, and District of Columbia. The survey questions targeted experiences associated with the implementation of RwHTS and the use of BIM for designing and constructing facilities over the last decade by the architectural firms. Based on the responses received, six firms were purposively selected for Phase II, which involved a case study approach that included meeting with the designers, conducting interviews, understanding general firm policies for capital projects, identifying factors that result in the adoption of RwHTS, and developing a process-based profile undertaken by the firm to understand how key decisions were made. By the end of this phase the researcher identified the factors that result in the adoption of RwHTS. In addition, the researcher also found that observability did not emerge as an attribute that played a critical role in the adoption of RwHTS, in comparison to the other attributes. The study also found that the current use of BIM did not result in the frequent adoption of RwHTS. Finally, the study was able to produce a generalized process map that depicted the steps undertaken during the design process for the adoption of RwHTS in capital projects. This study encompassed the basic principles of sustainability in the built environment, adoption of innovation, and Building Information Modeling use within the design industry.

DEDICATION

I dedicate my life’s most important achievement till now to my late grandfather. Thanks for your ever-inspiring conversations. I could not have succeeded without your love, support, and blessings

I also dedicate this dissertation to my family, friends, and mentors. Thank you all for your constant guidance, support, and being there when the path seemed dark. Without your encouragement and support I never could have achieved any of this.

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1.1 Introduction and Background

The built environment across the globe has been linked to a variety of negative impacts that threaten to affect the survival and prosperity of the human race (Keysar and Pearce 2007; Kibert et al. 2007; SOE 2011; WWF 2012). Historically, the planet has been perceived as an infinite source of natural resources and repository of waste, which has led to buildings that are extremely resource intensive (Kibert et al. 2002; McCoy et al. 2012). For example, the U.S. buildings were responsible for 72% of total U.S. electricity consumption in 2006, which is expected to rise to 75% by 2025. Buildings also are responsible for 13% of the total water consumed, 40% of non-industrial solid waste generated, 49% of SO_2 emissions, and 38.9% of CO_2 emissions (EPA 2009; Keysar and Pearce 2007; OFEE 2003). To meet the increasing energy requirements, the United States Department of Energy (USDOE) had proposed the construction of 100 coal powered power plants by 2017 in the country (Rowe 2011; USDOE 2010), but this is expected to have serious consequences for climate change. A fair amount of the total energy consumption, largely derived from nonrenewable fossil fuels and contributing to global climate change, occurs in the construction and operation of buildings (Watson 1979) which collectively represents 8% of United States Gross Domestic Product (GDP) (Kibert et al. 2002; Vanegas 2003). This total energy consumption indicates that facilities not only consume significant amounts of natural resources, but also contribute significantly to pollution over the life of the facility (Randolph and Masters 2008). This idea is confirmed by Vanegas (2003), where he states that along the course of accomplishing the objective, the Architecture, Engineering, and Construction (AEC) industry has severely impacted ecosystems and the capacity of the planet to support life.

To mitigate these effects, the phenomenon of sustainability within the Architecture, Engineering, and Construction (AEC) industry is gaining momentum. This concept of sustainability is viewed as one of the prime wedges which can offset or prevent the ill-effects of the built environment. There are various ranges of perspectives on how sustainability should be defined and operationalized with respect to the built environment, and those perspectives are extremely broad and sometimes conflicting (Pearce and

Vanegas 2002). According to Pearce and Walrath (2001), there are nearly 197 definitions explaining the concept of sustainability, but the most commonly acceptable definition and the one that will be used in this study, is that of the World Commission on Environment and Development (1987). It defines sustainability in the context of development as:

> *"…development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains within it two key concepts: the concept of needs, in particular the essential needs of the world's poor, to which overriding priority should be given; and the idea of limitations imposed by the state of technology and social organization on the environment's ability to meet the present and future needs."*

1.1.1 Sustainability in the AEC

Sustainability in the AEC industry is dependent on the paradigm shift in the usage of available resources to meet societal needs and aspirations, over time (Kibert et al. 2002). In order to achieve this change in paradigm, the concept of *"need vs. limits"* plays an important role, and each side of the equation offers opportunities to improve the sustainability of the built environment: reducing or better managing human needs, and improving technologies to stay within limits inherent in the environment (Chertow 2001; Commoner et al. 1971; Ehrlich and Holdren 1970; Ehrlich and Holdren 1971; Holdren and Ehrlich 1974). The ability of technology to better meet needs within the limits imposed by the environment can be improved by reorienting the way we design, select materials and systems for built facilities, and use them (Chertow 2001; Kibert et al. 2002; McDonough and Braungart 2002). Technological innovations that are more contextually feasible and ecologically responsive need to be adopted (Koebel 1999), in order to increase the sustainability of the built environment while meeting human needs, by the stakeholders of the facility including designers. Adoption of innovations within the AEC industry becomes important as it has often been mentioned that the concept of sustainability is a continuous process of evolution that entails constantly improving the systems through improved understanding and knowledge (Cary 1998). This also means continuously adopting innovations along the axis of time. Man-made systems are not sustainable over long periods of time, and require constant upgrades and evolution of processes and systems should take place (Kibert et al. 2002).

To contribute to increased built environment sustainability from a technological standpoint, it is essential to understand how and why innovations are successfully adopted in the design process so that more sustainable innovations can be promoted in the future. The distinction between an innovation and invention was first identified by Schumpeter in 1934 (Freeman 1989). Unlike inventions, which may have no particular application, innovations necessarily find applications in practice, offering opportunities to new enterprises. Since 1934, the concept of innovation, like sustainability, has undergone several variations in its basic definition. One definition of innovation used by multiple authors is "*the use of a non-trivial change and improvement in a process, product or system that is novel to the institution/firm developing the change"* (Blayse and Manley 2004; Freeman 1997; McCoy 2008; Schmookler 1952; Sexton and Barrett 2003; Slaughter 1998; Slaughter 2000). Still others define innovation as "*any practice or material artifact perceived to be new to the relevant adopting unit*" (Atun and Sheridan 2007; Czepiel 1974; Fichman 1992; Habets et al. 2006; Koebel et al. 2003; Rogers 2003). Innovation has been explicitly linked to the Architecture, Engineering, and Construction (AEC) industry because projects tend to generate novel and complex problems (Nam and Tatum 1992; Park et al. 2004), and as projects become complex, innovations become essential (Slaughter 1998). However at the same time it has also been pointed out that the AEC industry is slow towards adoption of innovations due to numerous factors (Sheffer 2011; Ball 1998; Habets et al. 2006; Winch 1998), thereby affecting the adoption/diffusion of sustainable innovations (Dewick and Miozzo 2004; Mitropoulos and Tatum 1999; Sheffer 2011).

1.1.2 Innovation

The success of an innovation within the society is gauged by its adoption and diffusion within the society (McCoy 2008), but the decision to adopt an innovation is not necessarily straightforward (Rogers 2003). Adoption in literature has been defined as "*A decision to make full use of innovation as the best course of action available"* (Rogers 2003). Within a society for any innovation, individuals over time may choose to adopt an innovation or not, and the process follows a sequence of steps with certain exceptions. The five steps associated with the decision of innovation are *"knowledge, persuasion, decision, implementation, and confirmation*" starting with the stage called *"Prior Conditions"* (Roger 2003). The individuals who choose to adopt an innovation are termed as adopters, and the ones who choose to do so early in the process of innovation are generally characterized as proactive, and can be conceptualized as innovators (Rogers 2003). On the contrary, for a single point in time on a diffusion curve of an innovation, non-adopters are generally the people who are reactive to a situation, generally decide against the innovation due to numerous reasons, and can be largely conceptualized as laggards and late adopters. For example, Venkatesh and Brown (2001) conducted a study regarding the factors driving personal computer (PC) adoption in American homes, which found that decisions driving adoption and non-adoption were significantly different. The study found that adopters were driven by fun and social outcomes from adoption, whereas non-adopters were influenced primarily by rapid changes in technology and the consequent fear of obsolescence. Hence, it is the individual characteristics of the potential adopter that determine whether the potential adopter will be an innovator or laggard (Zuberchen 2005). Thus, adoption of an innovation is not a straightforward process, and attributes of the innovation, contextual factors, and situational factors form an important context for the process of adoption of an innovation (Scott et al. 2008).

The adoption of an innovation is affected by multiple factors that can contribute to understanding why innovations are adopted. Attributes of the innovation, contextual factors, and situational factors form an important context for the process of adoption of an innovation (Scott et al. 2008; McCoy 2008). With regard to the innovations themselves, researchers from various disciplines have identified five general attributes of innovations that affect the adoption: observability, relative advantage, compatibility, complexity, and trialability (Askarany et al. 2007; Atun and Sheridan 2007; Black et al. 2001; Habets et al. 2006; Koebel 1999; McCoy 2008; Rogers 2003; Scott et al. 2008). At the same time, researchers have also pointed out additional attributes of innovation such as social approval, cost, communicability, divisibility, timing of commitment, profitability, supervision competency, and physical attributes that can be added to the ones initially identified (McCoy 2009; Slaughter 1998; Teng et al. 2002; Tornatzky and Klein 1982). For this study, the initially identified five attributes have been taken into consideration. Except complexity, all of the attributes of innovation are expected to be positively related to its diffusion and adoption (Askarany et al. 2007; Black et al. 2001; Roger 2003). Hence, one can conclude that observability positively influences adoption of innovation. This study investigates the significance of observability of Rainwater Harvesting Technologies and Strategies (RwHTS), in regard to their adoption. The other contextual and situational factors associated with the adoption of innovation have been excluded from the study. In addition, this study also used the fundamentals of innovation theory and the adoption of innovation. This study built on already established principles to define and evaluate one of the attributes with respect to one stakeholder of the built environment: designers. Scott et al. (2008) defines observability "*as the degree to which an innovation and its result are visible to others,*" and they suggest that the probability of adoption of an innovation is directly proportional to the ease of observing the particular innovation. Nieto and Perez-Cano (2004) defined observability "*as the extent to which technological knowledge can be observed and detected by people and generally depends on the type of innovation.*" Nieto and Perez-Cano (2004) also cited Zander and Kogut (1995) to state that observable knowledge is *"quickly transferred, easily accumulated, and hard to protect within an organization."* Nieto and Perez-Cano (2004) investigated how certain attributes of technological knowledge-codifiability, teachability, complexity, observability, and dependency-may influence the choices that organizations select for protection of their secrets. Black et al. (2001) examined the case of the consumer adoption of internet financial services using the attributes of innovation. The innovation attributes were found to be important determinants of consumer adoption decisions. However, observability could not emerge as the sole important factor in their study as the use of the internet for financial services was not visible for other members of the society, and was not widely discussed in a social setting. Habets et al. (2006) discussed the attributes of innovation in depth and then analyzed factors affecting the adoption of alternative transport technologies in the road construction industry. Observability was left out of the study because of its estimated insignificance in relation to road construction, as per the author of the paper. Askarany et al. (2007) in his study explained the link between the attributes of innovations and the diffusion of Activity-Based Management (ABM), a management tool, within an organization. Askarany et al. (2007) found that diffusion of ABM was significantly associated with the specified attributes of innovation addressed. With these studies conducted across the spectrum of discipline, there was an indication that the effect of attributes of innovation, specifically observability, over the period of adoption of innovations varied on a case by case and industry basis. These studies suggest that one attribute might be important for an innovation, but not necessary for Innovations towards sustainability (ITS), within the construction industry. Innovations towards sustainability (ITS) are specifically designed/developed with ecological parameters taken into consideration. This upgrade or the process of evolution for the ITS can either be incremental or radical depending on the situation and the technology in use at that particular point in time (Hines and Marin 2004; Hellstrom 2007; Rennings 2000). This also means that any ITS should not be viewed in isolation from its surrounding systems, but should be in concert with the whole system (City of Bellingham 2012), thereby implying that any *product/process* with sustainability as its goal should take into account a holistic approach and consider all direct and indirect factors affecting it and the facility. For this study product innovations have been defined as *"purchased technology or service that the stakeholder pays for but doesn't require change in behavior to derive desired outcomes"* (Langar 2008). And process innovations have been defined as *" Requiring behavioral changes/ changes in expectations/ adapting to different operating conditions that are otherwise preferred on the part of the stakeholder"* (Langar 2008). Until now we have noticed how the attributes of innovation have been linked with the various fields including construction. Further, to expand the existing research, this study identified whether or not observability could emerge as a sole attribute affecting the adoption of RwHTS. Rainwater Harvesting Technologies and Strategies (RwHTS) contribute towards reduction in water needs/consumption of the society, which lies within the scope of definitions established for ITS by Rennings (2000) and Hellstrom (2007).

While innovations in other domains have been extensively studied over the last 40 years (e.g., Rogers 2003; Tornatzky and Klein 1982), comparatively few studies have been conducted which analyze the effect of attributes of innovation upon adoption (Lee et al. 2003) of specific innovations/groups of innovations. In particular, few studies have previously been conducted to evaluate attributes of sustainable innovations specifically in regard to Rainwater Harvesting Technologies and Strategies (RwHTS). Table 1.1 discusses some of the studies identified in the literature with regard to the adoption of RwHTS, factors affecting the adoption of RwHTS, and the effect of the attributes of innovation on the process of adoption.

Table 1.1: Studies identified in the literature with regard to the adoption of RwHTS

Study	Unit of Analysis	Study intent and findings
He et al. (2007)	Farmers in China	The study aimed to identify factors that result in adoption of RwHTS. 12 factors were identified that contribute towards the adoption of RwHTS. The 12 factors identified were: Age, Level of education, Size of active labor force, Farmers positive attitude, Contact with extension workshops and experts, Obtained fertilizer, seed, and cash credit, Training received, Subsidy for the project, Involvement in the grain-for-green program, Diversity of irrigated crops, Walking distance of the water tank from the dwelling, and Status of village erosion.
Hendricks and Calkins (2006)	Designers and Owners in the Midwest United States	The study identifies factors, barriers, benefits, and conditions that lead to implementation of Green Roofs. The authors found that the design of green roofs was complex, not compatible with the existing roofing systems, could not be tried on an incremental basis, with not a great degree of quantified relative advantage. However, the green roofs offered some degree of observability not only as a product but also observability in terms of knowledge. Thereby the author stretched the boundary for observability by not limiting it to just visibility but also the knowledge aspect of it. The authors found that stakeholders who were informed about the innovation adopted it

		more.
Samaddar and Okada (2008)	General Population in Bangladesh and with respect to residential sector	The study analyzed the role of information exchange in the adoption of RwHTS and compared the effectiveness of mass media versus interpersonal sources. The study found that information exchange through interpersonal sources was more effective than mass media. Observation of innovation was not enough for the adoption of innovation in comparison to hearing, but at the same time was effective in spreading idea farther than hearing. Hearing was majorly effective in close communities whereas observability of innovation crossed boundaries, proving also effective.
White (2007)	General Population in Australia	The study identified the motivation for adoption of RwHTS. Except trialability; all attributes play a role in the adoption of an innovation.
White (2010)	General Population in Australia	The study identified the motivation for adoption of RwHTS. The results show cost and economy, the environment, household independence, advantages of rainwater harvesting as attributes that lead to adoption of RwHTS. Visibility, which was related with observability, was placed low.

1.1.3 Rainwater Harvesting Technologies and Strategies (RwHTS)

Rainwater Harvesting Technologies and Strategies (RwHTS) have emerged as top contender for innovations towards sustainability (ITS) within the water sector, even though there is little/no concurrence on technologies that should be considered as innovative (Partzsch 2009). At the same time, RwHTS have a long history of implementation and their use can be traced to early human settlements across certain civilizations (Athavale 2003; Frasier 1997; Han and Park 2007; Hicks 2008; Sivanappan 2001; Sultana 2007). The need for adoption of RwHTS has been highlighted by the fact that by 2025 about 5 billion people, or two-thirds of the entire human population, are expected to face scarcity of freshwater (Pacific Institute 2009; WWF 2012). Furthermore, researchers have also predicted that increases in current societal requirements of water consumption can cause irreparable damage to ecosystems and aquifer reserves of the planet (Covich 1993; Postel and Carpenter 1997; Postel 2000; Gleick 1993; WWF 2012). This implies that the current levels of consumption by the society are unsustainable and that the planet cannot support the needs of the society for an infinite period of time (WWF 2012), thereby stressing the need of adoption of technologies and strategies that mitigate the ever increasing needs of the human society. This opinion was shared by Ehrlich and Holden in their publications during the 1970's pointing towards this issue (Commoner et al. 1971; Ehrlich and Holdren 1970; Ehrlich and Holdren 1971; Holdren and Ehrlich 1974).. They explicitly mentioned that any renewable resource, in this case the water resources, have the potential to be converted into non-renewable system, depending on the rate of extraction and the rate at which the resources are consumed. As per the studies observed in literature, this idea no longer seems to be far-fetched in regard to water resources (Pacific Institute 2009; White 2010; WWF 2012). At the same time, RwHTS can be one of the ways with which such an impact can be mitigated.

RwHTS have been defined in numerous ways in literature (Arnold and Adrian 1986; Celmo and Presken 2010; Gaston 2010; Levario2007). Levario(2007) defined rainwater harvesting as "*the collection of rainwater without artificial inducement*" and Gaston (2010) defined it as *"the diversion or collection of precipitation in order to utilize it for some desired purpose."* Jothiprakash and Sathe (2009) cite Arnold and Adrian (1986) in context for the operationalization of rainwater harvesting and have defined it in a similar manner. For this study, Rainwater Harvesting Technologies and Strategies (RwHTS) was defined as "*the technologies/strategies used for the permanent collection of rainwater within a given capital project so as to enhance the water resources of the area and avoid storm water runoff and complications associated with it, on the ecosystem."* Hence, these technologies and strategies reduce the problem of over-consumption of the natural resources, cater to the increasing demand of resources, further offset the impacts on the ecosystem, and generate other environmental, social, and economic benefits (Oweis et al. 1999; Jothiprakash and Sathe 2009; Ibraimo and Munguambe 2007; Krishna 2003; TRHEC 2006; WWF 2012). The adoption of RwHTS contributes to increased sustainability of water resources by helping to offset increasing societal demands imposed upon the ecosystem (Covich 1993; Postel and Carpenter 1997; Postel 2000; Gleick 1993; WWF 2012). Additionally, they have also been referred to as a part of sustainable water management (Chatfield and Coombes 2007). Thus, RwHTS have the potential to replace centralized water supply and storm water disposal systems in some cases, which have been indicated to be highly unsustainable from the ecological and economic perspective across the globe (Partzsch 2009).

RwHTS have been cited in literature as cheap and simple, depending on their design and end use (Burt and Keiru 2009; City of Bellingham 2012; He et al. 2007; NRDC 2011; White 2007). At the same time, depending on the use of water captured and the type of RwHTS, the system can quickly become complex, and most of the time has many components associated with it (Celmo and Presken 2010; Hicks

2008; Mun and Han 2012), especially for projects which are non-residential in nature. Some of the basic components identified in literature that were associated with RwHTS are: catchment, collection, storage, transportation, distribution, and purification/treatment (Bellingham 2012; Celmo and Presken 2010; City of Bellingham 2012; Frasier 1997; He et al. 2007; Levario 2007; Sultana 2007). Furthermore, elements of RwHTS frequently mentioned across literature include: above and below ground tanks, bioswales, permeable pathways, green roofs, rain gardens, and others (Castleton et. al 2010; City of Bellingham 2012; Hendricks and Calkins 2006; Rowe 2011; Samaddar and Okada 2008; USGBC 2009).

Literature has segregated RwHTS into two major categories (City of Bellingham 2012; City of Tucson 2009), based on the way they are designed: passive and active systems. Passive RwHTS are designed to direct water to the allocated area without storing them in temporary containment systems and generally operate through gravitational flow. These systems do not require any infrastructure such as piping, metering, pumps, etc. to support them (City of Tucson 2009; City of Bellingham 2012; Gaston 2010). In contrast, active RwHTS are designed so that the water can be stored in containment systems to be used later. These systems may not solely rely on gravitational flow for operations and may use pumps, depending on the site size, condition, climatic conditions, etc. These systems do require infrastructure such as piping, metering, pumps, power supplies, etc. to support them (City of Bellingham 2012; City of Tucson 2009; Gaston 2010). Researchers have observed that the costs associated with passive RwHTS are generally much less than active RwHTS (City of Bellingham 2012) and so are commonly implemented in the southwestern United States (Gaston 2010). The study also tested the hypothesis that the adoption of passive RwHTS were more predominant than active RwHTS for the southwestern United States. Furthermore, the study also observed the adoption patterns within the industry, as to which RwHTS were adopted more and what characteristics were associated with the adopting units. Hence, the factors affecting the adoption of RwHTS from both the categories were studied along with the adoption process associated with these RwHTS. The adopting units were the designer firms geographically located along the southeastern coast of the United States.

RwHTS have often been addressed as a simple technology/strategy (Burt and Keiru 2009; City of Bellingham 2012; NRDC 2011), but the context within which RwHTS is adopted can complicate the technology/system (Angrill et al. 2012; City of Bellingham 2012; Chatfield and Coombes 2007; Ibraimo and Munguambe 2007; Jothiprakash and Sathe 2009). Even in states where RwHTS are permitted, the end usage of water is still dependent on the type of facility (LIDC 2008), thereby complicating the implementation process, especially for commercial facilities, and demanding the participation of professionals/experts such as designers in the decision process. Thus, designers play an important role while designing a facility to achieve the level of optimization and utilization from the adoption of technologies and strategies. Research suggests that owners/builders are able to enhance innovation within construction in a number of ways (Blayse and Manley 2004; Koebel 1999) and can sometimes be champions for sustainable innovations. However, as mentioned previously, RwHTS can quickly become complex, especially for commercial projects in developed countries such as the United States, thereby emphasizing the need to study the implementation of RwHTS from the designer's standpoint. Additionally, designers are an integral part from the conceptualization to completion of projects, and generally possess the expertise in most stages associated with the design (Ku and Mills 2010; WBDG 2012b) , especially of commercial projects. Such projects where sustainable innovations such as RwHTS are implemented are termed as green. Green buildings not only help conserve the natural resources and provide life cycle cost savings but also have the potential to improve the health of occupants (EPA 2012). However, for a successful commercial green project to accomplish its objective, appropriate design plays an important role. There are various aspects associated with what has been termed as effective design; some mystify it, and others point it out as a straightforward scientific process which should possess logical steps for decisions (Cross 2006; Mahdavinejad and Refalian 2011). To understand the adoption of RwHTS in holistic terms, it is also important to understand the design process followed by designers for green facilities, especially the ones where RwHTS are adopted.

1.1.4 Design

The process of design gas been defined a as "*iterative process where schemes are recognized, explored, revised and enhanced until a solution is identified"* (Sanders 1996). Others define design as an argumentative process based on empirical knowledge. Ku and Mill (2010) define design "as *a linear process that proceeds from schematic design through design development to construction documents."* Researchers have pointed towards various schools of thoughts that define the design methods, out of which three have been discussed most often: first generation, second generation, and the intuitive approach (Cross 2006; Mahdavinejad and Refalian 2011; Rittel 1973). The first generation considered the design method as "*systematic, rational, and logical"* way of approaching a problem (Archer 1965; Cross 2006) and was based on the philosophies of leading architects such as Louis Sullivan. In essence, this school of thought was based on the philosophy that form follows function. The second generation considered design method as an argumentative process based upon empirical knowledge, until form and function derive an "*agreeable coexistence*" (Rittel 1973). The by-product of the second generation was the third generation/intuitive approach which defined the design method as an intuitive process that tried to solve problems as they came (Cross 2006). Each of these schools of thought has been subjected to criticism with regard to the way design methodology had been defined. On one side first generation design methods were criticized for being too constricted thereby not helping the designers/architects; and on the other side, the third generation/intuitive approach was criticized for being too unclear and thereby creating more confusion (Cross 2006). At the same time it has also been stated that the process of design for conventional facilities is fragmented and disjointed (Kashyap et al. 2003), and was often described with a coarse set of milestones (Magent et al. 2005; Horman et al. 2006). Additionally, it was "*compartmentalized and linear*," with upstream design decisions impacting performance of the building over the lifecycle. Kashyap et al. (2003) states that the traditional design process encouraged isolation of stakeholders during the design and construction phase and the collaboration and information sharing among multiple stakeholders was sparse.

In contrast, the design of green facilities has been characterized as intensive and iterative between owner and designer, as a method of realizing the goals outlined for the project (Hackler and Holderen 2008). Most like projects began with identifying goals for a facility, which includes a statement of intent that occurs at the beginning of the project (Magent 2005). Furthermore, in literature, green buildings have been denoted as "*a front end loaded and human energy intensive exercise*" (Kobet et al. 1999). In the context of an integrated design process, green buildings are intended to encompass interdisciplinary collaboration from the very beginning of the design process, in order to achieve successful integration of building systems (Reed and Gordon 2000; Horman et al. 2006), while accomplishing the goals and aspirations of the community, within the allowable natural and economic resources. The need for an intense interactive and collaborative process is highlighted by the fact that various systems associated with the facility are interconnected. Deficiency of one system affects the performance of the other systems and thereby affects the overall goals prescribed at the beginning for the facility. Hence, the systems need to be analyzed on a holistic level in an integrated fashion using advanced simulation and analysis tools, which allow interplay between systems, and generate realistic scenarios. Thus, the process for designing a green building needs to incorporate checks and balances, identifying and determining the rationale prior to adoption of sustainable innovations, and employing holistic and systematic analysis of innovations to be adopted. Additionally, due to the highly collaborative nature of design of these facilities, interactions are expected to increase between stakeholders (Korkmaz et al. 2010). This enhanced interaction for green projects further increases the level at which the interdisciplinary collaboration occurs. This high level of interdisciplinary collaboration is required to conduct analysis and selection of systems and materials (Riley et al. 2004). This process of selection and analysis of materials and systems in a holistic scenario for green buildings further adds a layer of complexity to the project.

To reduce complexity associated with integrated design, visualization tools can facilitate better communication and collaboration among stakeholders, thereby improving the flow of information and ultimately improving the design process (Korkmaz et al. 2010). These tools can be very useful, especially during the design of green buildings that adopt sustainable innovations such as RwHTS to achieve sustainability goals. Building Information Modeling (BIM) is one such concept which can be used by the stakeholders, including the designers, to enhance the visualization of systems and materials, control the geometry of the built facility, and conduct environmental, site safety, and cost analysis (AGC 2007; Azhar et al. 2008; CRCCI 2007; Ku et al. 2008; Ku and Mills 2010). Most of the functions mentioned are important for designers from the schematic design phase, and BIM has the potential to be used for achieving those functions (Ku et al. 2008). Thus the functions offered by BIM compliment some of the objectives that designers try to accomplish during the design of a green building.

1.1.5 Building Information Modeling (BIM)

BIM is not only utilized as a product, but also as a process to contribute toward design, which most of the time is iterative among the stakeholders for all types of buildings (AGC 2007; Ku and Taibet 2011; NIBS 2007). Various organizations across the industry are trying to implement BIM, to utilize the potential offered by BIM which also meets their requirements. The AEC industry is embracing BIM as a tool that can assist in integrating the industry by eliminating inefficiencies and redundancies, improving collaboration, and enhancing productivity (Campbell 2007). As a result of this, the definitions of BIM have also been varying in the same way as sustainability, RwHTS, and innovation, discussed earlier.

As per the Whole Building Design Guide (WBDG), BIM is "*a digital representation of physical and functional characteristics of a facility which serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle from inception onward*" (WBDG 2012a). Autodesk has defined it as *"an integrated process built on coordinated reliable information about a* *project from the design through construction and operations"* (Autodesk 2009) up to the end of life for the facility. The American Institute of Architects (AIA) defines BIM as *"a digital three dimensional model linked to a database of project information, combining all information from the design inception to the facility management"* (AIA 2007). Thus we see numerous ways in which BIM has been defined. But within these different types of definitions, the following aspects emerge:

- Use of BIM as a combination of products/tools which produces three dimensional models, with enhanced visualization, and that is rich in information pertaining to the project.
- Use of BIM as an integrated process which enables flow of information between stakeholders up to and including the management/operations of the facility.
- A combination of product and process that helps stakeholder decide about the building over the life cycle.

One reason that can be associated with the numerous ways BIM has been defined is its ability to serve numerous stakeholders. In addition, BIM allows an integration/close collaboration among designers, owners, contractors, building specialists and others. BIM carries a wealth of information necessary for many aspects of sustainable design and green certification, which can be used by stakeholders across the various stages of the project (Azhar et al. 2008; Mahdavinejad and Refalian 2011; Siddiqui et al. 2009). Ku and Mills (2010) also stated that BIM can be used to enhance the sustainability of built facilities. For instance, for a green building, the percentages of energy consumed can be obtained. Various design options for sustainability can be pursued in parallel and automatically tracked in the model. Advanced visualization techniques can be used for solar studies and to produce 3D renderings and construction animations of a green project (Azhar et al. 2011; Strafaci 2008). Various aspects of BIM have been adopted by professionals to implement research and design, as it allows the integration of building systems among themselves as well as with external social, economic, and environmental contexts of the projects (Arayici et al. 2012; Krygiel and Nies 2008). Such digital information of building systems can be used by stakeholders to conduct necessary analysis for the lifecycle of the facility (Arayici et al. 2012). At the core of BIM software lies parametric modeling and building simulation that supports either manual or automated data sharing (Siddiqui et al. 2009). Vast probable permutations of the uses of BIM are possible and the derived benefits are dependent on the users as to what level they are willing to adopt the concept. As mentioned earlier, one of the biggest advantages with BIM is of visualization (Glick and Guggemos 2009; Campbell 2007; Staub and Khanzode 2007) of the building and components used, to the various stakeholders associated with the project. BIM also possesses the capability to represent a building with a three-dimensional model with every object having its own identity. This enhanced visualization not only helps the designers but also aids owners to perceive how the technologies will fit within the facility. Along with enhanced visualization comes the enhanced calculation ability of the model to quantify the savings to a certain extent, thereby resulting in improved design insights, risk mitigation, 4D and 5D analysis, clash detection, prefabrication, systems coordination, widening the search for solutions, improved integration in decision making, differentiation of objective and subjective judgment, and maintenance (Campbell 2007; Staub and Khanzode 2007; Korkmaz et al. 2010). These thereby help project stakeholders resolve interdisciplinary issues, conduct holistic system analysis, eliminate waste, and reduce cost escalation (Korkmaz et al. 2010). Design process modeling and use of visualization tools facilitate better communication and collaboration between stakeholders and further integration of design process (Korkmaz et al. 2010) and further help identify the owner aspirations established at the beginning of the project, thus validating the notion that BIM is not only a graphical representation tool, but is also a comprehensive information management tool (Campbell 2007).

1.1.6 Analysis of literature pertaining to BIM and Green Buildings

In addition, as seen in the preceding section, the process of BIM adoption on projects is somewhat in tandem to the process expected for the implementation of RwHTS on green projects. While reviewing literature, some of the similarities noted in regard to both BIM and green projects include:

- Need for adopting interdisciplinary approach and active stakeholder participation from the very beginning of the project (Arayici et al. 2012; Horman et al. 2006; Jerengen 2007; Nies and Krygel 2008).
- Need for a champion to support successful adoption, who at the same time will be technologically competent to resolve any issues that may arise (AGC 2007; Jerengen 2007; Mesnar 2011).
- Ability to provide benefit(s) to the adopting unit and also to the environment, if utilized properly (Azhar et al. 2011; Jerignan 2007; Krygiel and Nies 2008).
- Probability of suffering from partial adoption and in particular scenarios providing reduced benefits to the adopting units, since both are innovations.

1.2 Summary

With all the benefits of BIM and the potential to change the way the design and construction industry has operated, it comes with some drawbacks. The biggest disadvantage of BIM is that currently, certain tools are very labor intensive, complex, and costly due to the time associated with the creation of the models. Additionally, as discussed previously, some software are still not interoperable with each other and the information flow between the software is not parametric in nature. Hence, it is important that the applications of these tools must align, focusing on the areas that need interdisciplinary decision making, and enabling better systems understanding (Korkmaz et al. 2010). Thus, until now, we have seen that adoption of sustainable innovations seems to be one of the many solutions available to alleviate the impacts of the built environment on the natural environment. However, sustainable innovations such as RwHTS, have their benefits and seemingly are easy to install, but tend to quickly become complex for commercial projects. For these commercial projects, designers are involved from the beginning of the projects and have the ability to impact the decision of the projects (Ku and Mills 2010; WBDG 2012b). Also Hendricks and Calkins (2006) in their study found designers to perceive more highly about the benefits of green buildings and green roofs in comparison to the owners. The reason could be attributed to architect's higher experience with third party green building validation such as LEED (Leadership in Energy and Environmental Design) in comparison to owners. Also owners in the study indicated that environmental and social benefits of innovation were not a factor that contributed in the decision making. Hence, indicating that architects are more environmentally conscious than the owner/builders. In addition, designers also benefit from the use of BIM as they use it for the design of the facility along with enhancing the sustainability of a given project (Azhar et al. 2008; CRCCI 2007; Ku et al. 2008; Ku and Mills 2010).

For this study, we observe the adoption of BIM by architectural designers at both the product and process level. In addition, this study also determined whether the adoption of BIM had any effect on the design process followed for the green facilities. This study observed and analyzed the design process followed by designers for green buildings which adopted RwHTS. This analysis of design process gave the researcher a unique opportunity to understand how facilities, especially the ones in which RwHTS are adopted, were designed. It was realized that many engineering design processes have been created but no universally accepted design process has emerged, and no contemporary systematic studies presently exist of the design process undertaken for architectural design of green facilities. This study investigated the design process followed by the architectural firms who designed green facilities for private sector owners, in cases where those facilities adopted RwHTS. The limited understanding of the design process has also been highlighted by Horman et al. (2006) and then by Magent (2005) where they stated that the design process relating for every project of a high performance buildings were "*largely undefined and were analyzed*."

For this study, green buildings are operationalized as *"facilities that qualify to utilize and reduce the consumption of natural resources in an efficient manner, but do not necessarily need to be certified by any of the existing measurement tools established by LEED, NAHB green standard, Green Globe."* Additionally, the study also identified the factors that led to adoption of RwHTS and evaluated which attributes of innovation most influenced the adoption of RwHTS. The next section discusses the area of the scope of study.

1.3 Area and Scope of study

This study encompasses the following areas of research:

- Sustainability, specifically sustainable technologies and strategies in the built environment (RwHTS).
- Specifically attributes of innovations that affect their adoption.
- Design, specifically conceptual design and design development as part of architectural design of buildings.
- BIM, specifically as a tool employed in the integrated design of buildings by architects.

The focus of the research was on the niche that was the union of all these four area domains (Figure 1.1). Table 1.1 lists the sources indicated by each of the numbers in Figure 1.1.

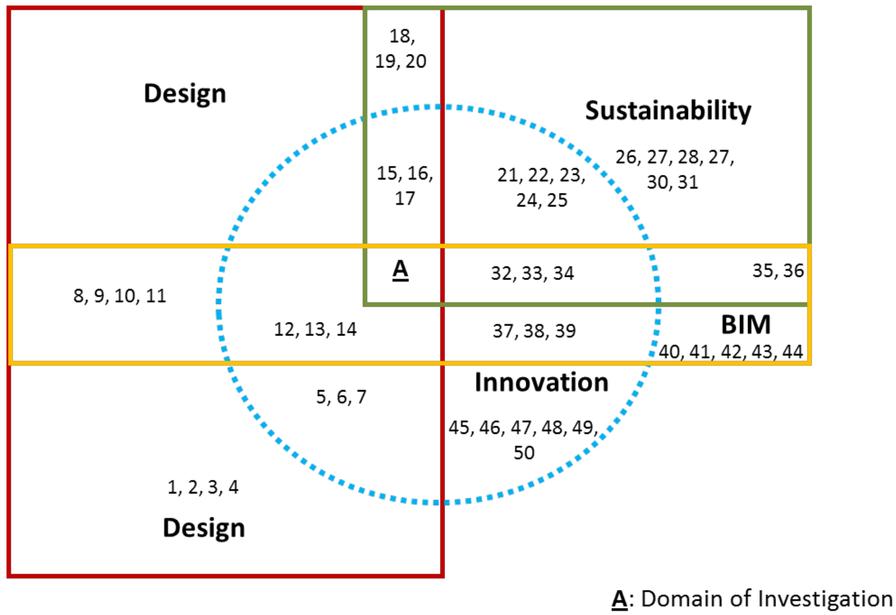


Figure 1.1: Domain of the study

This study investigated how architects designed green facilities that included RwHTS as part of their resource conservation strategy. The study aimed to understand the design process followed by the designers for the design of green commercial projects that included RwHTS in the last decade. The study also aimed to document changes in design process with the implementation of BIM, both as a product and as a process, to understand whether the use of BIM affected decisions to adopt RwHTS by affecting adopters' perceptions of its attributes. Specifically, the study identified factors cited by architects that played a role in the adoption of the selected RwHTS. The previous section discussed in detail the areas of study. The intention of the discourse was to elucidate the areas which were either included or excluded for the study. Figure 1.2 represents the overall areas and then from each area selects each sub-component that was included in the domain of the study. All the sections that were not encircled have been excluded from the study. As the figure suggests, there are four major areas that are a part of this study and one set of stakeholders.

Table 1.2: Legend for Figure 1.1

Sr. No.	Author (Year)	Sr. No.	Author (Year)
1	Cross (2006)	26	Randolph and Masters (2008)
2	Sanders (1996)	27	Pearce and Walrath (2001)
3	Roodman and Lenssen (1994)	28	Chertow (2001)
4	Rittel and Webber (1984)	29	Ehrlich and Holden (1970)
5	Georgiadou et al. (2012)	30	Ehrlich and Holden (1971)
6	Burgermaster (2010)	31	Ehrlich and Holden (1974)
7	Levario (2007)	32	Chen and Chang (2012)
8	Campbell (2007)	33	Geyer (2012)
9	Staub and Khanzode (2007)	34	Mc Graw-Hill (2010)
10	Autodesk Whitepaper(2009)	35	Krygiel and Nies 2008
11	Ku et al. (2008)	36	Siddiqui et al. (2009)
12	Yun and Schodek (2003)	37	Arayici et al. (2011)
13	Mahdavinejad and Refalian (2011)	38	Barlish (2011)
14	Arayici et al. (2011)	39	Jung and Joo (2011)
15	Ahn and Pearce (2007)	40	Glick and Guggemos (2009)
16	Bossink (2004)	41	Ku and Taibet (2011)
17	Keysar and Pearce (2007)	42	Mesnar (2011)
18	McDonough and Braungart (2002)	43	Ellis (2006)
19	Kibert et al. (2002)	44	Taiebat and Ku (2010)
20	Henderson (2007)	45	Atun and Sheridan (2007)
21	Rennings (2000)	46	Mahajan et al. (1990)
22	Hellstrom (2007)	47	Scott et al. (2008)
23	McCoy (2012)	48	Schmookler (1952)
24	Langar (2008)	49	Slaughter (1993) (1998)
25	Douglas (2008)	50	Toole (1998)

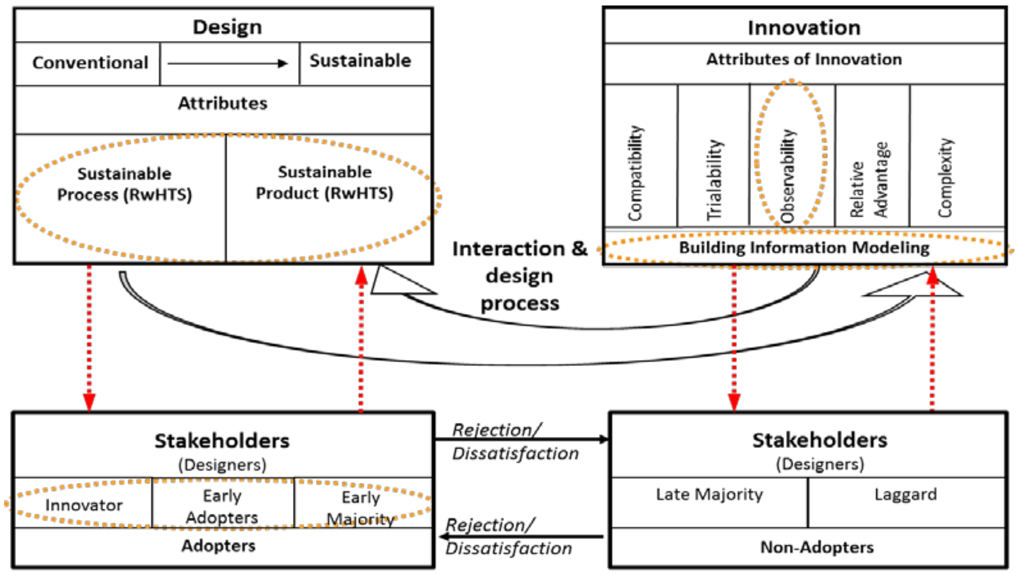


Figure 1.2: Scope of the study in regard to various parameters identified

1.4 Point of Departure

There is a growing appreciation for the adoption of RwHTS as it tries to fulfill the societal and economic water demands of the humanity. There are studies in the literature that investigate the adoption of RwHTS and the factors that lead to adoption of RwHTS from the perspective of residential owner(s), farmer(s), builder(s) or members of general society (Burt and Keiru 2009; He et al. 2007; Hendricks and Calkins 2006; White 2007; White 2010). However, during the course of literature review, the researcher was unable to locate studies that discussed the overall adoption and factors that determine the adoption of RwHTS by the architects especially for commercial facilities in the United States. Additionally, in the literature for adoption of innovation, researchers have pointed out the importance of attributes such as complexity or compatibility on the adoption process (Askarany et al. 2007; Habets et al. 2006; Nieto and Perez-Cano 2004). However, no studies were identified that discussed how observability as a single attribute has helped toward the adoption of RwHTS within the design and construction industry. One of the ways to identify the importance of observability in the process of adoption of innovations was by mapping the factors identified with the adoption of RwHTS upon the five attributes of innovation. This would discern the importance of each attribute of innovation in regard to adoption of RwHTS. It would also establish the importance of observability in regard to the adoption of RwHTS.

Apart from the factors that led to adoption of RwHTS, there is insufficient research in regard to the design process followed for green facilities where RwHTS is implemented. Moreover, this lack of information also continues with how this design process is altered by the use of BIM, which in itself adds a new paradigm of the design process. Researchers have noted that in order to improve the design process, one must first understand the design process for green facilities (Horman et al. 2006) to enable a deeper understanding of improvement impacts (Reed and Gordon 2000). Magnet (2005) also states that design process is re-discovered on a continuous basis. Hence, it was also identified that the design process for green buildings with regard to the AEC industry is largely undefined and there was a need to conduct a descriptive study that characterized the design process followed by the architects for private sector owners developing green facilities that utilize Rainwater Harvesting Technologies and Strategies (RwHTS). Additionally, the study also investigated the role of BIM in the design process to see whether there was any change in the process resulting from the use of this tool. Multiple authors have reflected that BIM is not just a product, but also a *process* that needs to be incorporated within a firm (Eastman et al. 2008; Jerignan 2007; Ku and Taibet 2011; Succar 2009). This study also provided a unique opportunity to observe how designers across the southeastern United States utilize BIM and what their thoughts are about the advent of technology on the design process. In addition, BIM reflects many attributes of innovation that are incorporated into a project. Attributes of innovation often results in the adoption of innovation. BIM enhances visualization of innovations (AGC 2007; Azhar et al. 2008; CRCCI 2007; Glick and Guggemos 2009; Ku et al. 2008; Ku and Mills 2010; Succar 2009) and visualization has been linked with observability of an innovation. Hence, the study also investigated if the use of BIM results in frequent adoption of RwHTS

The next section discusses the research questions identified for this study followed by a description of how the research has been organized for this study.

1.5 Research Questions

This section identifies the research questions for this section for this study, as follows:

1. What are the trends for implementation of RwHTS and BIM among designers in the southeast US?
2. Does observability play an important role in the adoption of Rainwater Harvesting Technologies and Strategies (RwHTS)?

3. How do designers use Building Information Modeling (BIM) to enhance the acceptance of RwHTS? As per literature, BIM enhances visualization and visualization has been linked with observability, so does the use of BIM result in frequent adoption of RwHTS?

1.6 Research Organization

This section discusses the layout of the subsequent chapters which encompass methodology, findings in the form of three journal manuscripts, and a validation and conclusion section. Each manuscript contains literature reviews of the individual topics covered therein, followed by point of departure, methodology applicable to the research area scoped out, results, future research, and conclusions.

Chapter 1: Introduction

Chapter one has presented a literature review, identified the area of study and the scope within the area of study followed by point of departure, and then put forth the three research questions.

Chapter 2: Methodology

Chapter two defines the methodology incorporated so as to successfully answer the research questions identified in the previous chapter.

Chapter 3: Implementation trends of Rainwater Harvesting Technologies and Strategies (RwHTS) and Building Information (BIM)) in the Southeastern United States

This is the first paper that was generated from the first section of the research methodology which analyzed the adoption patterns for RwHTS and BIM by private sector architectural design firms. In addition, multiple relationships between BIM/RwHTS with firm size and firm experience were tested. In addition other hypotheses were also tested. This paper employed a survey methodology and answered the first research question.

Chapter 4: Attributes of innovation affecting the adoption of Rainwater Harvesting Technology and Strategy (RwHTS)

This paper was generated from the second section of the research methodology. It identified factors for the adoption of RwHTS, explored the importance of observability as an attribute of innovation on adoption with comparison to other attributes, and characterized the effect of BIM on adoption of RwHTS. This paper incorporated interviews along with pile and quick sort method to evaluate the importance of various decision factors and answered the second research question.

Chapter 5: Chapter 1: Observing commonalities in design process and the influence of BIM adoption on the design process for green buildings

This paper was generated from the second section of the research methodology. It analyzes the design process followed by the architectural firms in the U.S. and the effect of BIM on the existing design process. This paper used a case based methodology and answered the third research question. The paper also identified the challenges and frustrations identified by the adopters of BIM

Chapter 6: Conclusion and Validation

Chapter six provides a summary of findings for all papers, establishing specific steps, tasks, limitations of this research, validation, and contributions of this research to the existing body of knowledge.

Chapter 2: Methodology

2.1 Introduction

The previous chapter established the need to conduct a study with regard to analyzing the attributes of innovation, specifically observability, and the need to characterize the design process followed by green buildings which adopt Rainwater Harvesting Technologies and Strategies (RwHTS). Furthermore, the previous chapter also described the various functions of Building Information Modeling (BIM) identified in literature and visualization was one of them. Additionally, the need for understanding the effect of BIM on the innovation adoption and design process was described. This chapter deals with the methodology for addressing these research needs. In order to complete this study successfully, a mix of fixed and flexible research design was undertaken, realizing the quantitative and qualitative nature of the data to be analyzed (Robson 2002). The study was broken into two major phases (Figure 2.1), with the second phase building upon the first phase, which has been mentioned in the subsequent section:

- The first phase of the study followed a survey methodology, which was quantitative in nature, as surveys often tend to be quantitative (Robson 2002). The main intent of this methodology was to:
    - Identify the trends for implementation of RwHTS and BIM among designers in the south-east US.
    - Test the hypothesis that visualization a function of BIM would be frequently adopted by the adopters of BIM, in comparison to the other functions of BIM.
    - Establish a set of participants from whom participants would be selected for the second phase.
    - Shortlist a set of RwHTS on which to focus for the next phase of the research.
    - Observe whether any relationship between the implementation of RwHTS and BIM could be ascertained. The observation of the relationship would be based on the information provided by the respondents in the survey.
    - Observe weather any relationship could be ascertained between the adoption of RwHTS/BIM and firm size/experience.

- The second phase followed a case study methodology which was quantitative and qualitative. The Phase II a was quantitative and Phase II b was qualitative in nature as case study approach is associated as qualitative (Robson 2002, Yin 2009). The main intent of this phase was to:
    - Further understand the relationship between the adoption of RwHTS and BIM as observed in Phase I.
    - Test the hypothesis that the adoption of BIM resulted in the frequent adoption of RwHTS.
    - Identify the factors which play a critical role in the adoption of RwHTS and then compare to innovation attributes identified from the literature.
    - Identify the design process for the green buildings.
    - Identify the effect of BIM on the design process.

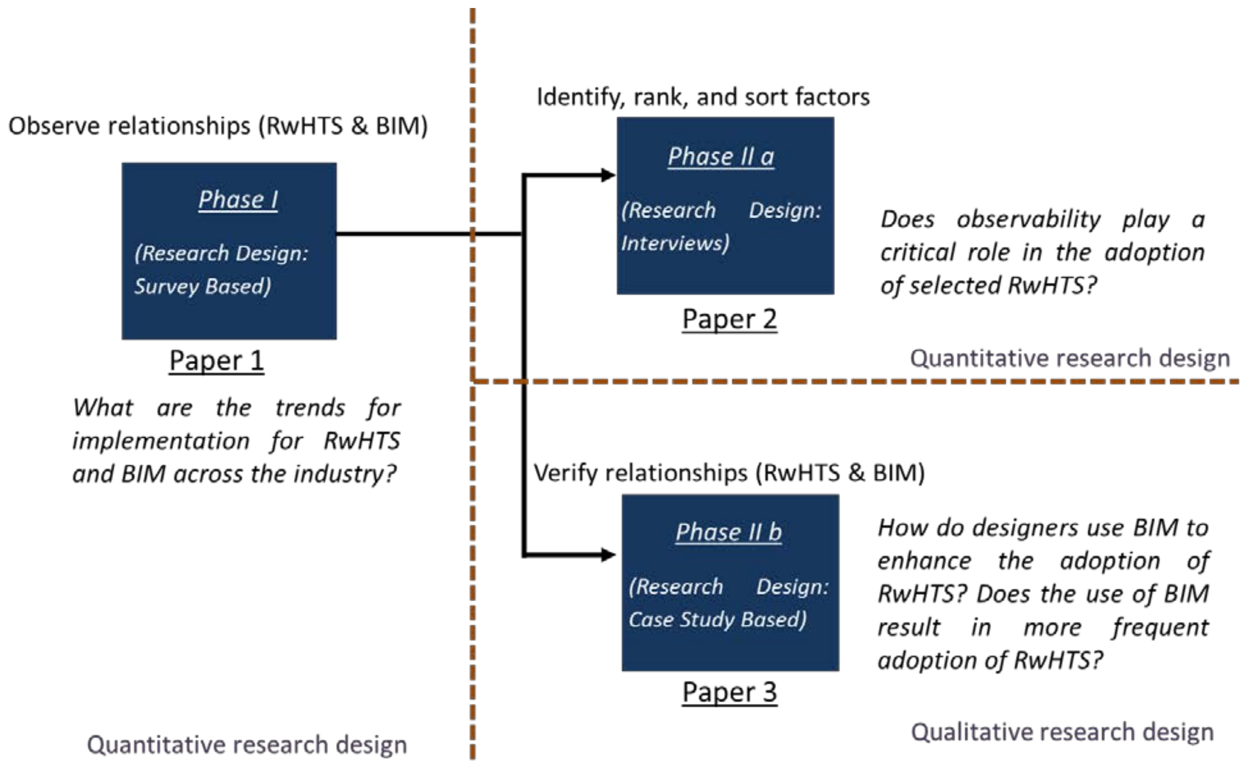


Figure 2.1: Overall methodology followed for the research

At the conclusion of the study, the findings enabled discernment of the differences in decisions, processes for design, and factors that affect the adoption of RwHTS. The study documented the ways in which the designers used BIM to enhance the adoption of RwHTS for the project. The following section discuss each of the two phases in greater detail.

2.2 Phase I

The first phase identified the trends for implementation of RwHTS and BIM among designers in the southeast US. In addition, Phase I also accomplished the following objectives:

- Investigate whether there was any relationship between implementation of BIM and RwHTS among designers.
- Identify the characteristics of the adopting units (architectural firms) such as size and experience
- Identify samples of design firms eligible and willing to participate in the second phase
- Test the hypothesis that passive RwHTS would be implemented more than active RwHTS
- Test the hypothesis that visualization a function of BIM would be frequently adopted by the adopters of BIM, in comparison to the other functions of BIM.
- From the list of RwHTS identified in Phase I, shortlisted certain RwHTS for Phase II

Respondents of the survey in Phase I were segregated into the following four categories, based on their responses to the survey:

- Adopters of RwHTS and BIM (+RwHTS+BIM)
- Adopters of RwHTS and Non-Adopters of BIM (+RwHTS-BIM)
- Non Adopters of RwHTS and BIM (-RwHTS-BIM)
- Non-Adopters of RwHTS and Adopters of BIM (-RwHTS+BIM)

Upon the completion of the segregation, three firms from each of the first two categories were selected using criterion sampling strategy, for a total of six firms, based on criteria discussed later in this chapter. The selected firms were analyzed during Phase II, using holistic multiple case study design. The process of segregation and selection of the sample, and shortlisting RwHTS for Phase II, marked the end of Phase I. Figure 2.2 depicts the overall methodological approach utilized for Phase I, including the three stages into which the phase was segregated. The three major stages were:

- Survey planning and development
- Survey implementation

- Data analysis

Each of the three stages has been described in the subsequent sections.

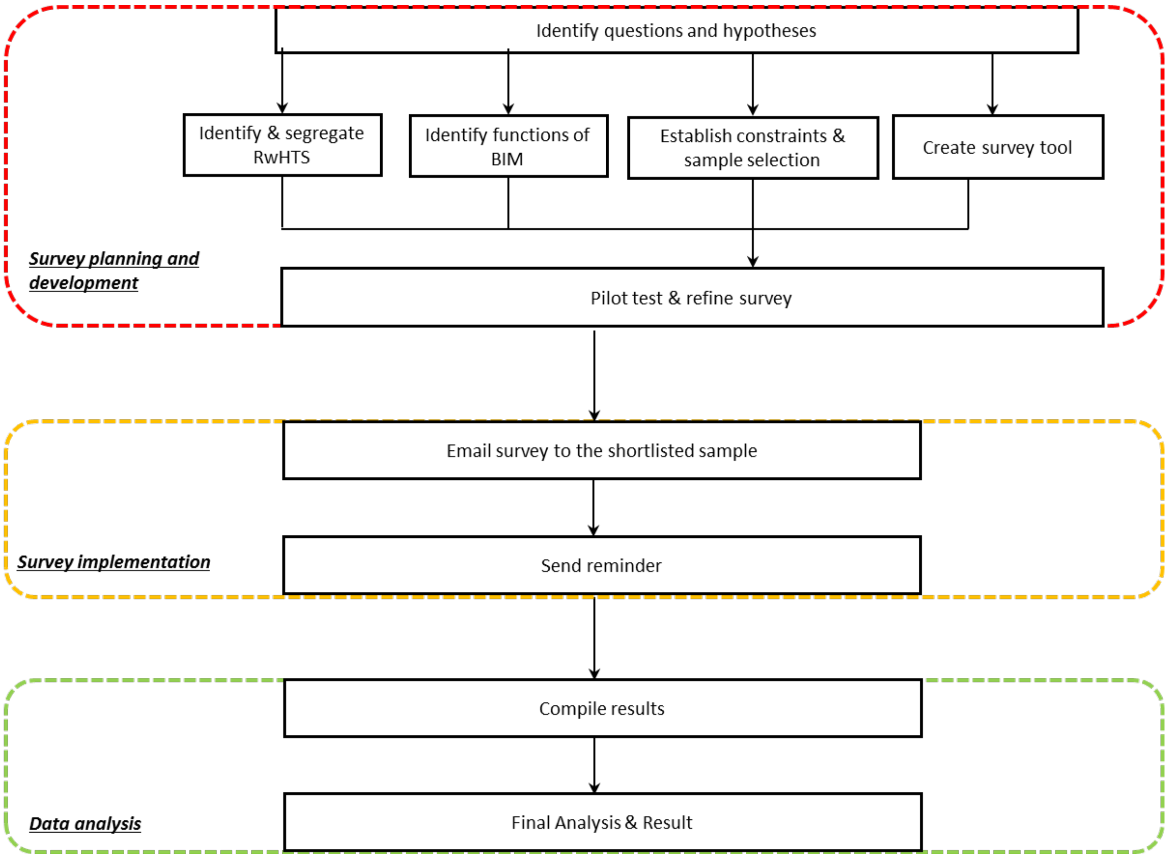


Figure 2.2: Research method for Phase I

2.2.1 Survey planning and development

The first stage aimed at planning, designing, and testing the survey which would identify the tends for the implementation of RwHTS/BIM. The survey was aimed at investigating the research question and hypotheses developed at the beginning of the study. This stage involved multiple steps, as follows:

- Identify questions and hypotheses
- Identify and segregate RwHTS
- Identify functions of BIM
- Establish constraints and sample selection
- Create survey tool
- Pilot test and refine survey

2.2.1a Identify research question

The main aim of this phase was to identify the implementation trends for RwHTS/BIM. In addition, as mentioned in the prior section the Phase II was building upon the Phase I, and the output from the Phase I were used as inputs for the Phase II. The first step aimed at identifying the scope, which included shortlisting the questions and hypotheses to be investigated, during this phase of the study. These questions and hypotheses were identified after extensive literature review as depicted in chapter 1 and 3 of the document and were relevant to Phase I. The answers to the identified questions and hypotheses paved the way to Phase II.

Hypotheses:

- Visualization, a function of BIM, would be most adopted
- Passive RwHTS would be adopted more than the Active RwHTS
- Implementation of BIM is related to the size of the firm
- Implementation of BIM is related to firm experience
- Implementation of RWHTS is related to implementation of BIM
- Implementation of RWHTS is related to firm experience
- Implementation of RWHTS is related to the firm size
- Implementation of RWHTS is related to firm's experience with federal projects

Questions:

- What implementation patterns are observed for RwHTS and BIM?
- How do respondents fit with respect to the four adopter categories of BIM and RwHTS?
- Which of the list of RwHTS identified in Phase I should be included in Phase II?

Once the set of hypotheses and questions were determined, the next step involved operationalizing and identifying RwHTS for this study.

2.2.1b Identify and segregate RwHTS

RwHTS for this study have been defined as the technologies/strategies used for the permanent collection of rainwater, within the site, so as to enhance water resources of the area and avoid storm water runoff and complications associated with it on surrounding ecosystems. In order to identify various RwHTS, LEED (Leadership in Energy and Environmental Design) reference guide was used, since many federal and state agencies mandate LEED, as a measuring tool to evaluate the sustainability of a building (Bossink 2004; DuBose et al. 2007; Hendricks and Calkins 2006; Langar 2008). Additionally, LEED is established within the construction industry and widely applied in the United States (Hendricks and Calkins 2006; Langar 2008). Hence, the most current version at the time of study, LEED NC V3.0, was used to identify potential RwHTS, with a specific focus on Sustainable Site Credit 5, 6, and 7, and Water Efficiency Credit 1 and 2. Hermeneutic method was used for analyzing the data from the reference guide and developing descriptive definitions for the identified RwHTS. Hermeneutics method has been indicated to cover "*the understanding and interpretation of linguistic and non-linguistic expressions"* (Ramberg and Gjesdal 2005). This method has been cited for conducting literature review (Boell and Cecez-Kecmanovic 2010), and was accepted for the identification of RwHTS. Figure 2.3 depicts the process to identify RwHTS. This method was adapted from Boell and Cecez-Kecmanovic (2010), and is generally cyclic in nature. For this study, the loop was completed only once and was not a continuous iterative process. And hence the more appropriate version for the representation of steps covered in this method was pyramidal, as each step was supported by the previous step, as depicted in Figure 2.3. The first step in this process included identifying the baseline document which in this case was the LEED Version 3.0. After this, all the information was compiled into two categories, namely usable and unusable. Any credit which discussed the rainwater conservation was termed as usable and the rest of the information was discarded. All the credits which discussed information pertaining to rainwater conservation were reviewed carefully and this led to the identification of RwHTS. Once the RwHTS were identified, other sources in literature which discussed RwHTS were identified. Upon identification, descriptive definitions for each of the RwHTS were developed. All the identified RwHTS and their descriptive definitions were analyzed by an expert reviewer, to refine and further validate. The nine RwHTS identified for this study were: Above-ground rainwater storage, Bioswale, Constructed wetland, Extensive green roof, Intensive green roof, Permeable pathway, Rain garden, Retention pond, and Under-ground rainwater storage. In addition, literature identifies two major categories of RwHTS based on the way they are designed: passive and active systems (City of Bellingham 2012; City of Tucson 2009).

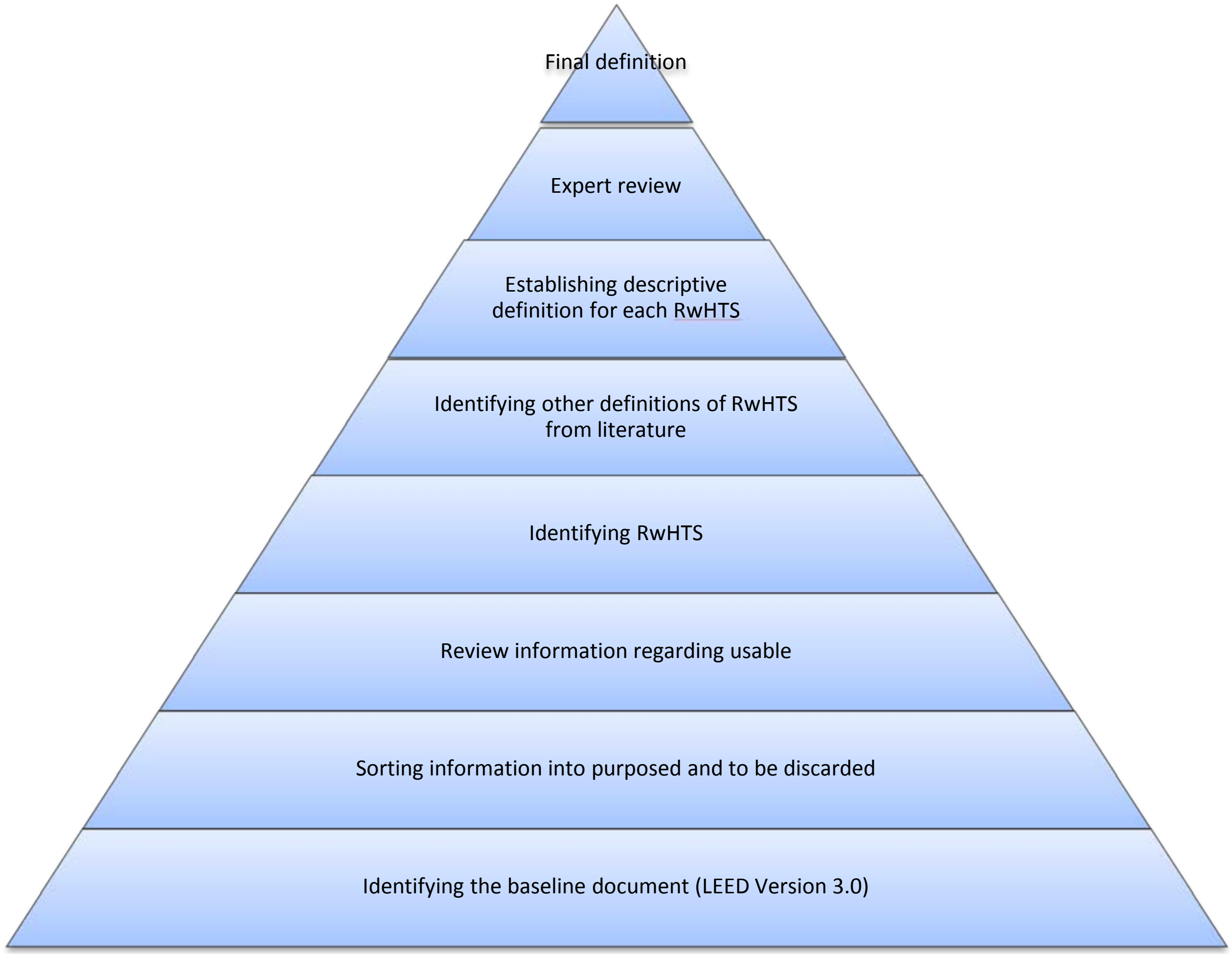


Figure 2.3: Method used to identify and develop descriptive definitions for RwHTS

Passive RwHTS are designed to direct water to the allocated area without storing them in temporary containment systems and generally operate through gravitational flow. These systems do not require infrastructure such as pressurized piping, metering, pumps, etc. to support them (City of Bellingham 2012; City of Tucson 2009; Gaston 2010). In contrast, active RwHTS are designed such that the water can be stored in containment systems so that it may be used later. These systems may not solely rely on gravitational flow for operations and may use pumps, depending on the site size, condition, climatic conditions, etc. These systems do require infrastructure such as piping, metering, pumps, a power supply, and other components to support them (City of Bellingham 2012; City of Tucson 2009; Gaston 2010). Based on the definitions established for active and passive RwHTS, all nine RwHTS were analyzed in terms of the individual descriptive definition, requirements to install and operate. Upon analysis of RwHTS, a sort of nine RwHTS was conducted into active and passive RwHTS. Upon completion of this sort, it was subjected to expert review to further refine and validate the sort. After identifying and segregating the RwHTS, the next step involved establishing the functions of BIM which would help identify most of the research questions identified earlier.

2.2.1c Identify functions of BIM

The main intention of this phase was to identify the various functions associated with the adoption of BIM. As observed in Chapter 1, BIM can be defined in numerous ways, due to various attributes depicted by it. In addition, BIM is considered both as a modeling technology and an associated set of processes to produce, communicate, and analyze building models (Eastman et al. 2008; Ku and Taibet 2011). With these variations, it also possesses various functions which represent the concept of BIM. For BIM, seventeen different functions were established for which it could be used by contractors in the AEC industry (Ku and Taibet 2011). Further expanding on the works of Taibet and Ku (2011), in which the functions of BIM relevant for contractors were identified, a list of eighteen functions relevant to architects were identified and further developed with an expert professional from the industry. They developed a list which consisted of the following functions: clash detection, constructability evaluation, construction drawings development, database information management, design of complex structures, estimation, facility management, initial presentations, interior environmental analysis, LEED, municipal code, parametric design, performance optimization, site analysis, restoration and renovation, sustainable design, value engineering, and visualization. Once all the eighteen functions associated with

BIM relevant to architects were identified, it marked the end of this step. The next step involved the selection of population and establishing constraints.

2.2.1d Establishing constraints and sample selection

After identifying, defining, and segregating all RwHTS and functions of BIM, the next step involved identifying the population and establishing constraints in order to derive a survey sample. The general population for this study was architectural firms operating in the United States. The United States Department of Labor defines architects as "*licensed professionals who transform space needs into concepts, images, and plans of buildings to be constructed by others"* (WBDG 2012b). Furthermore, architects have been defined by the National Council of Architectural Registration Boards (NCARB) as "*professionals who have been trained in the art and science of the design and construction of buildings*" (NCARB 2009).

Designers within architectural firms are also responsible for coordinating various stakeholders during the design phases. This is highlighted by the fact that they not only have the obligations but also comprehensive training in holistic problem-solving, and an understanding of broad cultural concerns which makes architects suited for the leadership of design teams (WBDG 2012b). Furthermore, architects are involved from the early stages of project feasibility to help define a program, choose the site (if needed), and provide expertise with associated tasks (WBDG 2012b), and it is precisely at this phase when sustainability strategies on a broad level are identified and considered. Although there are numerous professional associations for registered architects, AIA has been the leading professional membership association for licensed architects since 1857 (AIA 2012a). The principal objective for the creation of AIA was to "*create an organization which promotes not only the profession but also the scientific and practical perfection of its members"* (AIA 2007). Additionally, AIA collaborates with the National Council of Architectural Registration Boards (NCARB) to "*develop and recommend standards regulating the practice"* for architecture (AIA 2007). At the same time, not all licensed architects/designers are AIA members. In addition, being a licensed architect is controlled by each state and AIA membership is not a prerequisite for it (AIA 2010; BLS 2012). Sources cite that AIA has more than 83,000 licensed architects/designers and associated professionals (AIA 2011) and has a comprehensive database of architects practicing in the United States (AIA 2012b). Hence, for this study, registered architectural firms who were members of AIA was the first constraint established for the selection of sample.

The second constraint was the geographic location of the architectural firms. Firms geographically located in the seven states which included Georgia, North Carolina, South Carolina, Florida, Virginia, Maryland, and the District of Columbia were selected to be a part of the sample. Most of the areas in the selected states, at a macro level, receive nearly the same amount of precipitation, which is about 40-60 inches annually (WRCC 2012). In addition to the similarity in precipitation, the selected states also represented the hot humid and mixed humid zones. These zones have been defined by PNNL and ORNL (2010) in their study and have many similarities compared to other climate zones which occur in the United States.

Hence to sum up the following two constraints were established for the selection of the sample:

- The architectural firms selected must be registered with AIA
- The architectural firms selected must be geographically located in one of the seven states which fall on the southeast coast of the United States. The seven states included Georgia, North Carolina, South Carolina, Florida, Virginia, Maryland, and the District of Columbia

Once the constraints were established, it led to identification of the sample. The next step involved the creation of the survey tool itself.

2.2.1e Creation of the survey tool

After identifying RwHTS, functions of BIM, establishing constraints and selecting a sampling frame and selection criteria, the survey tool was created. Web based survey methodology was chosen to answer the research questions and hypotheses identified for Phase I because it has the ability to collect detailed results, comparable from large numbers of individuals, and enabled established generalizability of information (Werner 2004).

Of the many methods available to conduct the survey, for this study, emailing invitations to participate in a web-based survey was chosen because of the following major factors highlighted in literature:

- Most of the general population in the United States has internet access (Sheehan 2001). As a professional AEC industry segment, the target population is even more likely than the population at large to have internet access. Hence, this approach was likely to generate a significant response relatively quickly compared to other methods.

- Emailing invitations to participate in an online survey generates rapid response (Flaherty et al. 1998).
- The method allowed awareness of the number of emails undelivered to the sample by the researcher (Sheehan 2001).
- Value obtained by emailing a survey outweighed other methods, especially with respect to cost, time, and the number of respondents covered (Dillman 2007).

However, despite these factors, certain studies in literature highlighted that emailing a survey was not always successful and should be used with caution. Since the study aimed at a relatively large sample size of about 2000 firms, the advantages outweighed the disadvantages (Kiesler and Sproull 1986; Opperman 1995; Schaefer and Dillman 1998; Sheehan 2001; Watt 1999). Accordingly, emailing invitations to the online survey appeared to be the best course of action. Significant care was taken to ensure that the survey length was kept to a minimum. Researchers suggest that the length of a survey is one of the factors that determines the response rate (Fowler 1995; Sheehan 2001; Yammarino et al. 1991). At times, the length of a survey has been found to be an important factor used to decide whether or not to participate (Tomasokovic-Devey et al. 1994), although other researchers have found that survey length did not affect the response rate (Brown 1965; Bruvold and Comer 1988; Mason et al. 1961) or that longer surveys yielded better responses. However, for this study, the researcher chose to focus on minimizing the time commitment required by participants, and the survey was designed in such a manner that it could be completed in 10-12 minutes, provided the respondent was familiar with the organization.

Upon the completion of the study, the tool was pilot tested and refined on the basis of comments received from the respondents. The next section discusses it in greater detail.

2.2.1f Pilot test and refine survey

Once the survey tool and the sample for the study were finalized, the survey was pilot tested. The sample for the pilot test was architectural firms which were selected on the basis of previous working relationships. Hence, for this study, the pilot survey was sent out to ten architectural firms and two weeks were provided for their feedback. One reminder was sent upon the end of the two week period. At the end of the pilot study, a 60% response rate was received. The feedback received from the pilot study respondents was compiled and segregated into the following four categories:

- Comprehension of the survey
- Aesthetic of the survey
- Technicality of the survey
- General Comments

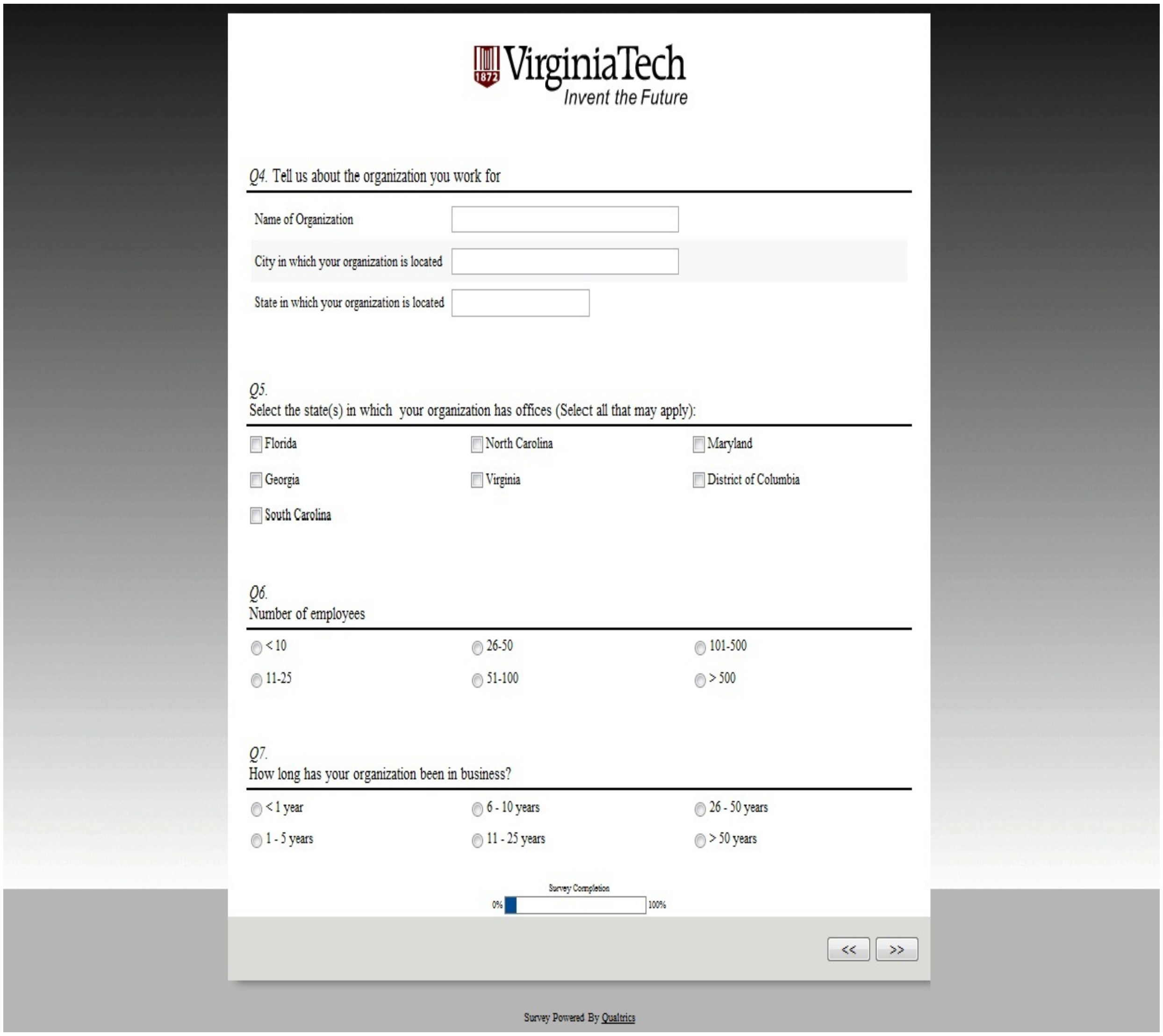
Consequently, the survey was further refined based on feedback received. In addition the tests demonstrated that it took 13 minutes on average for the respondents to complete the survey, which was determined to be an acceptable time commitment. Aesthetics and the consistency of certain questions in the survey are some of the other additional factors which affect the response rate, as per Sheehan (2001). Hence, the survey was designed in accordance with aesthetics and consistency. Figure 2.4 depicts the appearance of the survey to the sample. In addition, questions emailed to the survey sample have been depicted in Appendix A. Once the survey tool was further refined based on the comments received, it marked the end of this stage. The output of this task was a refined survey ready for implementation, which fed into the next stage: conducting the survey with the identified sample.

2.2.2 Survey implementation

Once the survey tool was designed and pilot tested, the next stage involved deploying the survey to the sample, which was selected as per the criteria established in the previous stage. This section describes the methodology incorporated to send the survey to the population along with the manner in which the reminder was sent. This stage was segregated into two major steps: email survey and reminder for survey. Succeeding section discusses each of the two steps in detail.

2.2.2a Email survey

This was the first step in this stage and it aimed at emailing the survey to the identified sample. Two variables were consistently identified in literature which were relevant for this step and affected the response rates for the studies analyzed. The two variables were "*pre-notification*" and "*follow-up*" of the survey (Sheehan 2001). For this study, the respondents were not pre-notified. However, a cover letter was sent as an email, which included an abstract about the study and a link to the survey. The cover letter was personalized to the individual participant in order to achieve a higher response rate. Respondents were offered the opportunity to have the aggregated results shared with them without revealing individual responses. Appendix A lists the survey questions.



VirginiaTech
Invent the Future

Q4. Tell us about the organization you work for

Name of Organization
City in which your organization is located
State in which your organization is located

Q5.
Select the state(s) in which your organization has offices (Select all that may apply):

Florida
North Carolina
Maryland
Georgia
Virginia
District of Columbia
South Carolina

Q6.
Number of employees

< 10
26-50
101-500
11-25
51-100
> 500

Q7.
How long has your organization been in business?

< 1 year
6 - 10 years
26 - 50 years
1 - 5 years
11 - 25 years
> 50 years

Survey Completion
0% 100%

<< >>

Survey Powered By Qualtrics

Figure 2.4: Appearance of survey to the respondents

2.2.2b Reminder for survey

Six weeks after the initial email, a reminder was sent to the firms which had not responded to the survey or had partially completed the survey. Literature indicates that the response rate increases up to 40% (Comer and Kelly 1982; Murphy et al. 1990) by sending a reminder email. Specifically in email surveys, Sheehan and Hoy (1997) found that the follow-up email increased the response rate by 25%. For this study, the total number of responses increased by about 45% after the first reminder. For this study, only one reminder was sent. After four weeks from the first reminder, the survey was closed. The results of the survey then fed into the next step: compiling all the information and analyzing it, so that the objectives outlined prior to the beginning of this phase could be accomplished.

The next stage aims at discussing the steps utilized in compiling and analyzing the final results for this phase.

2.2.3 Final analysis

The last stage aimed at compiling and analyzing all the information collected from this process. The goal was that all the information compiled and analyzed would be able to address all the identified hypotheses and questions discussed earlier.

2.2.3a Compile results

All the results were downloaded from the website in a spreadsheet form and the results were compiled. At a generalized level, it was observed that the response rate for the survey was about 19%. However, upon closer inspection of the responses, it was found that 4% of the respondents had not completed the survey, in regards to the questions asked. These respondents skipped most of the questions. Accordingly, the effective response rate came down to about 15%. As per some studies, this response rate can be considered insufficient, but as Sheehan (2001) points out in his study, a good response rate on an internet-based survey is difficult to obtain due to numerous factors such as increased internet sampling by investigators, information overload on the respondents, compensation of time, etc. With these factors pointed out in the literature that led to decreased response rates for email surveys over the years, the calculated percentage of about 15% was accepted. The next step in this section discusses the process for analyzing the survey responses.

2.2.3b Final analysis and results

Once all the results downloaded were analyzed in the excel spreadsheet, the data was analyzed to develop descriptive statistics along with generating a relationship between implementation of BIM and RwHTS. In order to test the relationship between BIM and RwHTS, Chi Square Test was used. According to Carter and Carter (1999), "*Chi-Square is a statistical test used to compare observed and expected data to analyze specific hypothesis*." Chi Square Test can be used when hypothesis has two independent variables compared to establish a relationship between them. Another criterion for the selection of Chi Square is when the population is at least ten times as large as the sample, and that was the case in this study. There are two types of Chi Square Tests: namely Chi Square Test of Goodness of Fit and Chi Square Test of Independence. Of the two, Chi Square Test of Independence was used, since the two categorical variables formed a single population. In addition the test of independence was used to determine if a significant association between the two variables could be established. It was used to prove/establish a relationship between the data collected and the hypotheses established.

Calculation for the Chi Square Test of Independence involves six steps: (1) state the hypotheses, (2) calculate expected value, (3) calculate Chi Square value, (4) calculate degree of freedom (5) compare value against distribution table and (6) interpret results. For this study, the following hypotheses were tested:

- Implementation of BIM is related to the size of the firm
- Implementation of BIM is related to firm experience
- Implementation of RWHTS is related to implementation of BIM
- Implementation of RWHTS is related to firm experience
- Implementation of RWHTS is related to the firm size

After establishing the hypotheses, the expected value (f_e) for the individual hypothesis was calculated as (Total of row of observed value (f_o) table X Total of Column of observed value table)/ Sum of all values in the observed table (N). Later Chi Square value was calculated by using the following formula: $\sum (f_o - f_e)^2 / f_{e.}$ Once the Chi square value was found, degree of freedom (df) was calculated.

Degree of freedom= (Total # of columns from the observed table -1) x (Total # of rows from the observed table -1).

After calculating the degree of freedom, we compared the Chi Square value against the values in Chi Square distribution table with (df) degree of freedom and 0.05 probability level. If Chi Square value exceeded the critical value in Chi Square distribution table for 0.05 probability level, then the null hypothesis was rejected. Chi Square identified whether variables were independent or related. However, the strength of the relationship was not established by Chi Square. After deriving the results for all hypotheses mentioned above, Cramer’s V test was used to test the strength of the relationship. Cramer's V is a measure of the strength of relationship for matrices larger than 2 x 2. It measures the degree of association between the values of the row and column variables on a scale of 0 to 1 as depicted in Table 2.1. The previously mentioned hypotheses were tested to answer the following questions:

- What are the trends for implementation of RwHTS and BIM among designers in the southeast US?
- Is there any relation between the implementation of BIM/RwHTS with architectural firm's characteristics such as the size of the firm and experience of the firm in the market?
- Is there any relation between the implementation of RwHTS and BIM?

Table 2.1: Relation of Cramer's V with the strength of relation (Texas Tech University 2013)

Value of Cramer's V	**Strength of relationship**
0.80 or 1	Very Strong relationship
0.60-0.80	Strong relationship
0.40-0.60	Relatively strong relationship
0.20-0.40	Moderate relationship
0.10-0.20	Weak relationship
0.00-0.10	Negligible relationship

Apart from hypotheses testing utilizing the Chi Square Test, a generalized descriptive statistical analysis was conducted to address the remaining hypotheses and questions identified earlier.

Hypotheses:

- Visualization, a function of BIM, would be most adopted
- Passive RwHTS would be adopted more than the Active RwHTS
- Implementation of BIM is related to the size of the firm
- Implementation of BIM is related to firm experience
- Implementation of RWHTS is related to implementation of BIM
- Implementation of RWHTS is related to firm experience
- Implementation of RWHTS is related to the firm size
- Implementation of RWHTS is related to firm's experience with federal projects

Questions:

- What implementation patterns are observed for RwHTS and BIM?
- How do respondents fit with respect to the four adopter categories of BIM and RwHTS?
- Which of the list of RwHTS identified in Phase I should be included in Phase II?

Three firms from each of the categories of adopters of (+RwHTS+BIM) and adopters of (+RwHTS-BIM) were selected based on the following criteria:

- Most adopters within their respective category (+RwHTS+BIM) and (+RwHTS-BIM)
- Willing to allocate time from their schedule to be a part of the study
- Willing to share information regarding the firm's operation
- All selected participants adopting the shortlisted RwHTS

The three shortlisted firms identified in this phase were analyzed in detail, in the next phase, using the case study methodology. In addition, as a backup, an equal number of organizations were selected in case the selected firms did not decide to participate. At the same time, five RwHTS were also shortlisted from the comprehensive list of nine RwHTS identified in the previous section, because of the following reasons:

- It was realized that some RwHTS were specialized enough to require input from other disciplines such as hydrology or geotechnical engineering in their selection and design. The implementation of selected five RwHTS did not require any such specialization.
- For the five selected RwHTS, architects had the most say since these systems were the least technical in nature.

The five RwHTS whose adoption would be studied in greater detail in the next phase were: green roofs (Extensive and Intensive), rainwater storage tanks (Above and Below ground), and permeable pathways. During the analysis of the data collected in the survey, there were indications that a relation between RwHTS and BIM from the perspective of the adopting unit (design firm) might be present. To validate these indications, the researcher used questions during the Phase II b to confirm the indications. In order to ascertain that BIM actually resulted in the implementation of RwHTS, architects were asked questions during the interview which helped solve this research question. Also, understanding the design process via process maps and then comparing the process maps across the board helped establish whether BIM influenced adoption of the identified RwHTS.

2.3 Phase II

Based on the data received from the previous phase, this phase aimed to identify following research questions:

- Does observability play an important role in the adoption of Rainwater Harvesting Technologies and Strategies (RwHTS)?
- How do designers use Building Information Modeling (BIM) to enhance the acceptance of RwHTS? As per literature, BIM enhances visualization and visualization has been linked with observability, so does the use of BIM result in frequent adoption of RwHTS?

The methodology shown in Figure 2.5 depicts the research process followed for this phase, which was implemented using the case study method. Figure 2.5 was developed on the basis of the case study model, cited from Yin (2009). The second phase aimed at conducting case studies of three shortlisted organizations per category.

The two categories considered for this study were adopters of (+RwHTS+BIM) and (+RwHTS-BIM). Hence, a total of six organizations – three each – were selected. Considering that there may exist scenarios where an organization may fail to participate, as a backup an equal number of organizations were selected as potential replacements for the second phase of the project. The subsequent sections discuss the methodology used to solve the research question, identified at the beginning of this stage, including the five major stages into which the phase was segregated. The five major stages were:

- Design data collection protocols
- Conduct and analyze pilot study
- Conduct case study
    - Site visit 1
    - Site visit 2
- Conduct analysis for each case
- Analyze and draw cross-case conclusion

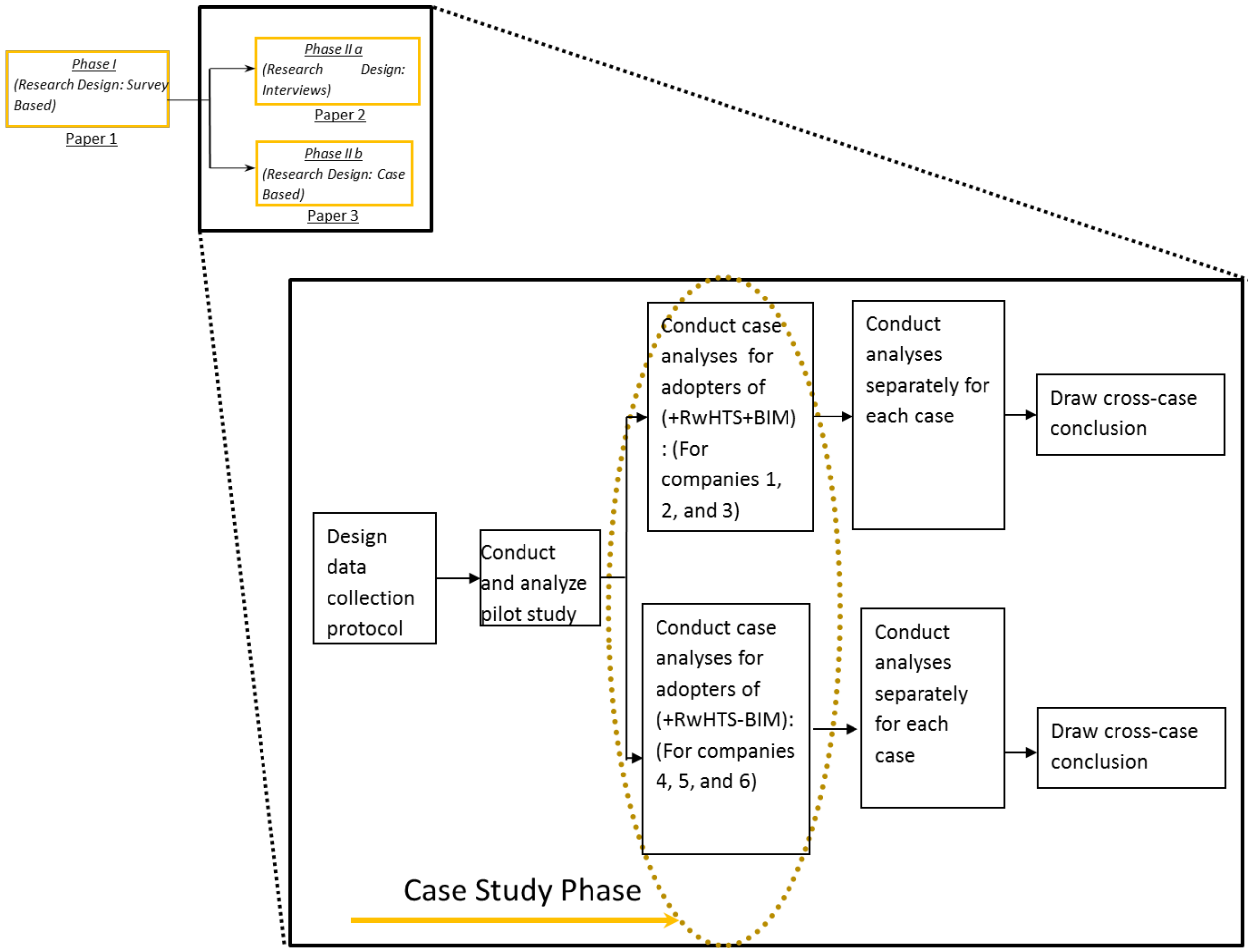


Figure 2.5: Research process (Modified from Yin 2009)

2.3.1 Design data collection protocols

Multiple case studies with a holistic design approach were used to resolve the research question identified at the beginning of this phase. The case studies had as their objective understanding the design process adopted by the organization, which would in turn help answer the established research questions. To support this, Yin (2009) states, "*If a case study examines the global nature of an organization or a program, a holistic design will have been used*." Since the study is based on observing multiple cases from a holistic perspective, a multiple case with holistic design method has been used for this study. The unit of analysis for this study was the design firm, and within each case, the general design process was examined in terms of several projects undertaken by the firm using that design process. Figure 2.6 captures this form of design that was used in this research. Herriott and Firestone (1983) states that the evidence from multiple case studies are more compelling and regarded as robust, thus providing another reason for the selection of the mentioned method. Two different sets of protocols were established at this stage of the study (Appendix B and C), which would act as the guiding documents for collecting data about each of the two categories of case studies (+RwHTS+BIM and +RwHTS-BIM).

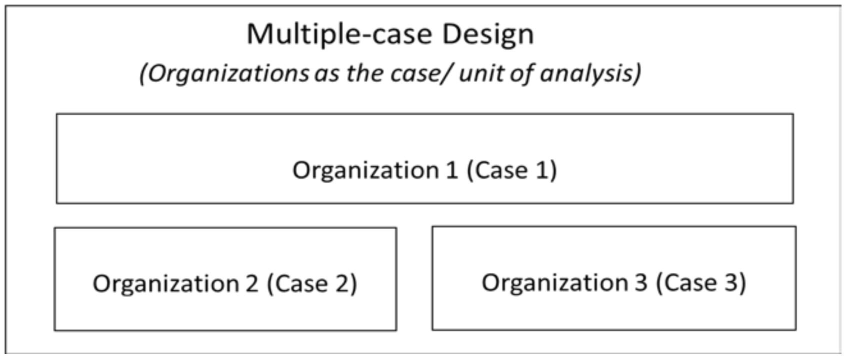


Figure 2.6: Form of design used for case study in this research (Modified from Yin 2009)

The initial questions for both protocols were the same and focused on the general design process followed by the firms when adopting RwHTS into facilities and the factors that result in the adoption of RwHTS. These questions covered:

- Attributes that play key roles in the adoption of the RwHTS
- Reason for the adoption of the RwHTS
- Design process followed from the project initiation to completion
- Process of adoption of the RwHTS in projects
- Current thoughts and comments on the applied RwHTS
- Barriers toward adoption of the RwHTS

For firms that had also adopted BIM, the protocol included additional questions aimed toward understanding how the adopters used BIM both as a product and a process for facilities that had adopted RwHTS. These questions focused on:

- How BIM is used
- BIM and its role in the adoption of RwHTS
- BIM and change in design process from convention

A series of two site visits were planned to each firm so as to capture all the required information. The following techniques were employed as part of the data collection:

- Establishing initial contact via email followed by a telephonic conversation to confirm participation and to schedule the two site visits.
- Video recording all the responses of the respondents, subject to approval of interviewees.
- Manually noting any comments made by interviewees regarding factors that lead toward the adoption of RwHTS, how BIM assisted in the process, and thoughts about the continued adoption of RwHTS.
- Process mapping the design process for the adoption of RwHTS, and identification of stages where BIM was implemented using the process map as a point of reference.

2.3.2 Conduct and analyze pilot study

After developing the protocols, a pilot case study was conducted as the first step to test performance of the established protocols. Since the two protocols were same except for the additional questions regarding BIM adoption, a pilot case was purposively selected which had adopted both RwHTS and BIM. The pilot case had the same demographic attributes as the actual case study firms. For the pilot study, the process of selection of the sample was based on Yin (2009), who states that pilot study respondents can be selected on the basis of convenience, access, and geographic proximity. This selection process based on the proximity and previous working relationship allowed for more prolonged and less structured relationship between the researcher and the pilot case respondents.

Contact with the pilot study respondents was established via telephone on a personalized basis for making an appointment to spend a day with the designer(s) to understand how the design process and selection of RwHTS are done for a selected project using the questions in the protocol (Appendix C). The interview was an informal session, as at this stage the researcher aimed to identify and eliminate possible problems with the protocol. Data was collected using the same techniques as proposed in the protocol.

The main aim of the pilot test was to not only study the responses received during the site visit, but to also study the appropriateness of the questions asked, and incorporate feedback received from the respondent. Following recommendations were received from the pilot study respondent to improve protocols:

- Reduce the time intended to be spent with the architectural firm.
- Ensure that not more than one firm is scheduled per day as there is a probability that the time of the scheduled meeting could be delayed.
- Ensure that the location of the camera does not affect the respondent and the ability to respond to the questions.
- Validate the process map upon completion as there is the potential for information being misinterpreted by the researcher.
- Revise the language of the questions to make it more simplistic.

The recommendations provided by the pilot study respondent helped to enhance the quality of the questions and made it more appropriate in regard to the sample. Once the protocols were further refined and tested based on the comments received, the actual case studies could begin. The next section provides an insight on how the case studies were conducted.

2.3.3 Conducting case study

Figure 2.7 depicts the tasks involved in conducting each case study. This stage was divided into two site visits per organization, for two categories (+RwHTS+BIM and +RwHTS-BIM), with three firms in each category. Upon completion of each task, as depicted in the figure, an output was generated in form of a document. Accordingly, a total of 12 site visits were conducted in the phase II. Prior to conducting the first site visit with each organization, contact with the individual who completed the Phase I survey was established via email/telephone and an appointment was scheduled to spend time with the principal designer of the organization. The site visit aimed to understand the design process for the adoption of RwHTS. Prior to the site visit, the representative of each organization were made aware of the aims of the study and provided the opportunity to ask question(s) and request clarification(s).

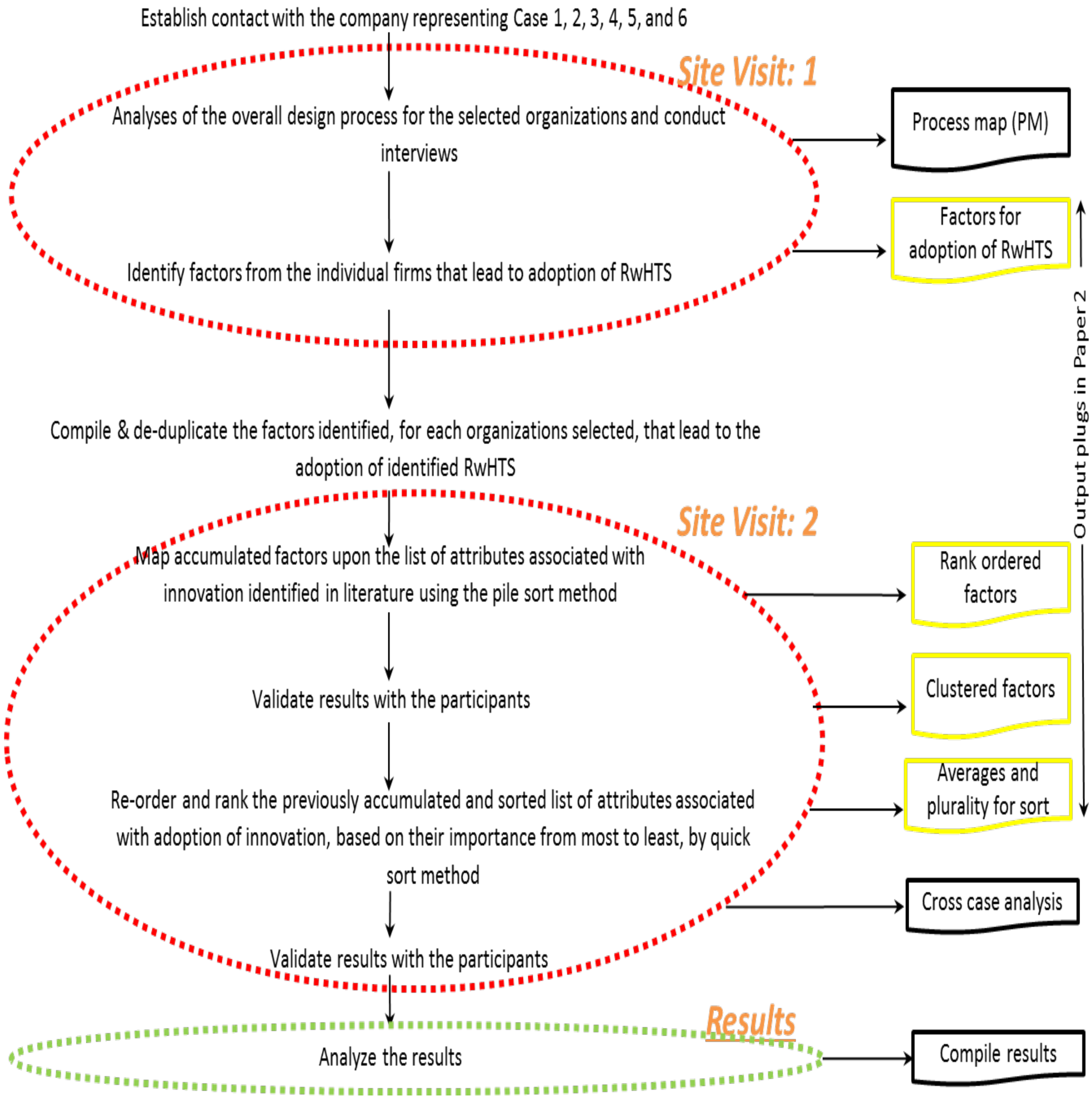


Figure 2.7: Tasks involved during the Phase II of the study

2.3.3a Site visit 1

The aim of the initial site visit was to understand the overall design process followed by the design firm. This information was captured by means of process maps, video recordings, and hand-written notes. Process maps provide an overview of the work-flow associated with identified task(s), depicts objective(s), and the project stage(s) at which the steps are used (NBIS 2007). It also helped identify and compile tasks and provided precedence to the identified tasks. Other sources mention the process map as a visual aid for picturing work and depicting relationships/links between identified tasks (Klotz 2008). Furthermore, these maps are considered as a strategy which supports transparency (Womack 2003; Bauch 2004; Klotz 2008). Since this study aimed at identifying the design process associated with the design of facilities which implemented RwHTS, a tool was required which could identify all the tasks associated with the design of a facility and also establish a relationship between the identified tasks. Process maps were found to possess the required qualities that were necessary to answer the research questions. Hence, all the information regarding the design process followed at the organizational level was noted and depicted in the form of process maps. In addition, the researcher also identified factors which affected the adoption of the selected RwHTS by interviewing the participating designer(s). Figure 2.8, also an example of process map, depicts the protocols followed for site visit 1. Additionally, Table 2.2 provides the legend for the process map generated.

The first part of the site visit aimed at understanding the operation of the organization and how the design process was conducted in general from the project initiation to the generation of construction documents. Interviewees were asked to describe how the process occurs in their own words, during which the interviewer constructed a process map representing their description. At the end of their description, additional questions were asked to further clarify the process and relevant factors (Appendix B and C lists the questions asked in each category). After the process map was developed based on the information gathered from the interviewees, it was validated with them by asking them to go through it once again. If the process map was incorrect, then the corrections were applied and re-validated. After the process map for design at the organization level had been validated, the interviewees were asked to comment whether design at the organizational level was considered the same as design at the project level for projects adopting the RwHTS. The intention was to observe if there was any difference between the design process followed generally by the firm for green buildings and then for projects where RwHTS were implemented and investigate if such cases were treated as typical/atypical cases for the firm. The last step of the first site visit aimed at identifying the factors that supported adoption of selected RwHTS in projects. The respondents were asked to explicitly mention factors which resulted in the adoption of the selected RwHTS, as per their experience. All the responses were duly noted and simultaneously video recorded.

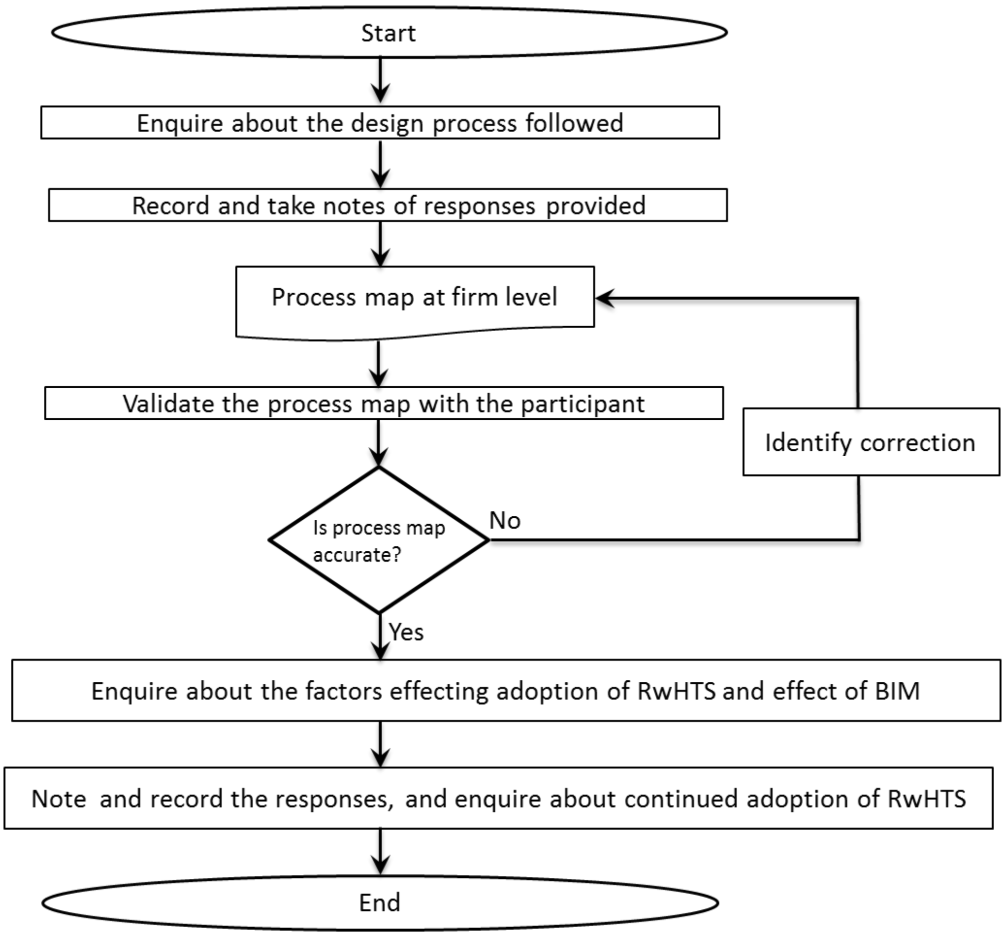
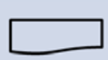


Figure 2.8: Process Map depicting protocols for site visit 1

Table 2.2: Legend for the process maps

Symbol	Explanation
	Collate the information
	Decision node
	Document produced in the step
	Process/ Step in the whole study
	Sorting of information collected

Thus, the first site visit yielded the following information for each organization:

- Process map depicting the overall design process where RwHTS were adopted.
- Difference between the typical design process followed by the organization and the design process where RwHTS and/or BIM were used.
- List of factors that affect the adoption of selected RwHTS.

Between the end of site visit 1 and beginning of site visit 2, the researcher spent time compiling and analyzing the collected data for all the selected organizations. Figure 2.9 depicts a process map that identifies activities and their relationships.

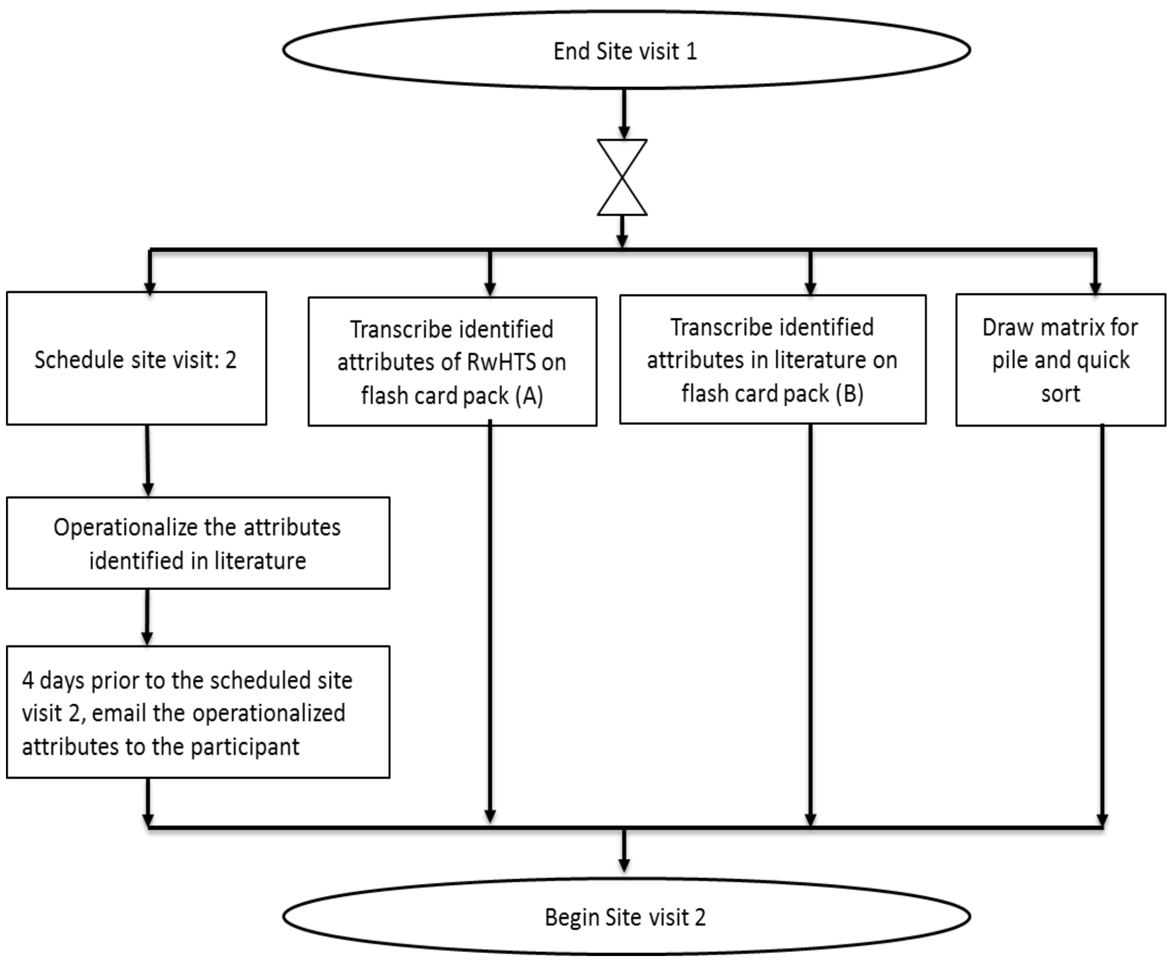


Figure 2.9: Process map depicting activities expected to be accomplished prior to site visit 2

Upon completion of all site visits for three firms, each representing (+RwHTS+BIM) and (+RwHTS-BIM) categories, the researcher compiled the identified factors that affected adoption of the selected RwHTS. All the factors identified from the respondents during the first stage were compiled and de-duplicated. By de-duplication, it meant that all factors that were mentioned more than once were ignored during the process of transcribing. Hence, all the compiled factors were transcribed onto flashcards, with each flashcard listing only one factor. These flashcards would be used during the second site visit along with a matrix to conduct pile and quick sorts. In tandem, the researcher prepared additional information to be delivered to interviewees prior to the second site visit, including an operationalized list of attributes of innovations identified from the literature. At least four days prior to the second site visit, this list of attributes was emailed to participants so that they could review it in preparation for the second interview. The respondents were asked to read through the information provided and write down all the questions that they might have. The process of sort was not revealed to them until the second site visit began.

Of the various methods, this study used similarity and ordered data. Similarity data has been defined where "*informants judge similarities amongst study item"s* and ordered data consists of *"ranking of data on a scale by informants"* (Weller and Romney 1988). Similarity data collection method was intended to help determine whether observability plays a critical role in the adoption of selected RwHTS. Ordered data method was aimed to rank the factors that play a critical role in the adoption of the selected RwHTS. Both similarity and ordered data can be achieved using various methods.

Similarity data can be achieved through methods such as pile sort, triads, rating scale, balanced incomplete bock design, etc. (Weller and Romney 1988). Pile sort within itself possesses two variations, including the constrained and unconstrained. For this study, a constrained pile sort was chosen to achieve similarity data because subjects can categorize items into a specific number of categories, with reference to certain criteria. The reference criteria were the definition to the five attributes of innovation (relative advantage, trialability, observability, complexity, and compatibility) that was provided to the respondents prior to sort. In addition, this method can handle large numbers of factors to sort, which some other methods fail to do.

Ordered data could be achieved through numerous methods, which included: triads, rating scale, full and partial rank ordered, quick sort, balanced incomplete bock design, etc. (Weller and Romney 1988).

For this study, quick sort was chosen because of multiple advantages. Firstly, a lot of information can be sorted quickly and it is productive. For this study 26 factors were identified by the respondents that affect in the adoption of the shortlisted RwHTS. Secondly, it is also possible to identify how similar information is for one respondent compared to another. Hence, considering the aims and constraints of the study, pile and quick sort were determined to be the best methods available to sort the data based on similarity and order, in order to resolve the identified research questions.

These compiled factors, once ranked by respondents during the second site visit, comprised a set of parameters which played a critical role in the adoption of selected RwHTS. The next section discusses the second site visit and how their questions were answered, and the process followed for the sort, which was conducted.

2.3.3b Site Visit 2

The aim of the second site visit was for the participating architects to rank the compiled factors and then sort them based on their similarity to the five attributes of innovation identified in the literature. The second site visit was less intensive, in terms of time and effort, than the first site visit. Figure 2.10 depicts the protocols followed by the researcher during the second site visit in form of process map.

At the beginning of the site visit, the researcher provided a hard copy of the list of operationalized attributes, previously sent via an email, to the participants and asked them to go through the list. The participants were provided as much time as they liked to analyze the attributes and, at the end of the analysis, were asked if they had any questions. All clarifications were made at this stage and the process of pile and quick sort explained. Then each participant was provided a pack of flashcards that listed each factor affecting the adoption of RwHTS, which the researcher had compiled, de-duplicated, and transcribed in Phase I based on data from the previous site visits. Next, the participants were asked to sort the flash cards into five piles corresponding to the five general attributes of innovation identified from the literature (Observability, Relative Advantage, Trialability, Compatibility, and Complexity). If the participant felt that any flashcard was equally similar in meaning to more than one pile, then copies of the flash card were provided so that the card could be included in more than one pile. Additionally, the participants were asked to think aloud while they conducted the sort so that the researcher could document their thought process. At the end of the sort, a cross tabulation of the sorted attributes was developed using the previously prepared sort matrix, and the results were shared with the participant to validate the sort. This activity resulted in a mapping of the factors that impacted the adoption of RwHTS to the attributes of innovation identified in literature. A general observation during the sort was made that some piles were bigger than others. This information provided an insight into which of the five attributes of innovations encompassed most of the factors that affected the adoption of the RwHTS.

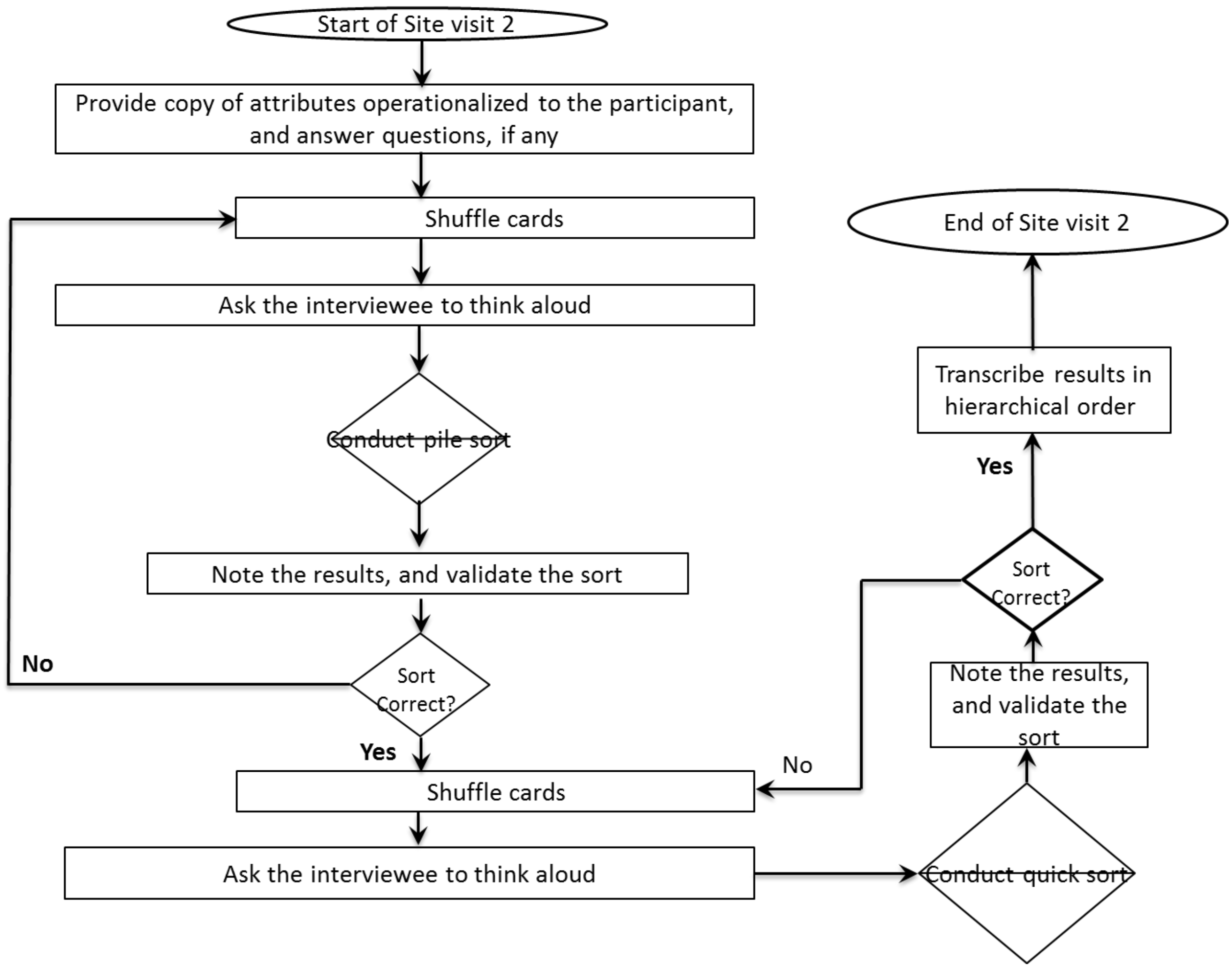


Figure 2.10: Process map depicting protocols for site visit 2

The next step of the second site visit aimed at ranking the factors identified by the participants, based on their relative importance for the adoption of the selected RwHTS, i.e. from most important to the least important. The participants were asked to sort the cards into an order that reflected the relative importance of factors with regard to the adoption of RwHTS, from most important attribute to least important attribute. This process of quicksort was conducted by asking the participants to select a card from the pile and name it as a standard card. Then all the remaining flashcards were compared to the standard and divided into two piles: the cards "greater than the standard" and those "less than the standard". This process was repeated for each pile formed in the process, until all factors transcribed on the flashcards were ordered based on the relative importance they had on the adoption of the RwHTS.

At the end of this stage, results were shared with the participants to validate the results, and were given the opportunity to adjust the sort as appropriate to reflect their understanding of relative importance. As per Weller and Romney (1988), validation is essential for this type of strategy as the methodology has been subjected to criticism in terms of validity. Hence, conducting validation after the sort was of prime importance. By the end of this task, each participant had identified and ranked factors that impacted the adoption of RwHTS from their perspective. Hence the compiled results of this stage would help answer the research question of whether observability played a critical role in the adoption of selected RwHTS. Additionally, another outcome would be the identification of the factors which were perceived to be critical for the adoption of selected RwHTS by the participating designers.

2.3.4 Conducting analysis for each case

The completion of the case study phase marked the end of the data collection from the six separate cases. The next phase focused on conducting detailed analysis for the information collected for each of the cases. The main aim of this phase was to conduct analysis of the data collected within each individual case to address the following research questions:

1. Does observability play an important role in the adoption of Rainwater Harvesting Technologies and Strategies (RwHTS)?
2. How do designers use Building Information Modeling (BIM) to enhance the acceptance of RwHTS? As per literature, BIM enhances visualization and visualization has been linked with observability, so does the use of BIM result in frequent adoption of RwHTS?

All the information compiled from each case was noted separately in the form of text-based transcripts, process maps, and matrices from quick sort and pile sort processes. Process maps were used to derive the manner in which firms designed a building that implements RwHTS with or without the use of BIM. The matrices were utilized to keep track of pile and quick sort of factors which were associated with the adoption of the selected RwHTS. Last but not least, text in the interview transcripts was used for the other questions asked during the two site visits to each firm. On the basis of the case-by-case analysis, the researcher noted the differences between the organization's design process for the two categories

(+RwHTS+BIM) and (+RwHTS-BIM), which represented all six selected cases. All the identified differences were coupled with explanations obtained from the designer(s) during the data collection phase for validation. In addition, for each case, the attributes of innovation were sorted and ranked based on the responses received from the process of sorting and ranking respectively. The validated set of case data for each of the six firms was the major output of this task, and fed into the next activity of drawing cross-case conclusions.

2.3.5 Analyzing and draw cross-case conclusions

The final task of the research was to develop comparisons across the two categories (+RwHTS+BIM) and (+RwHTS-BIM) to address the research questions mentioned in the beginning of this phase. The associated research questions aimed at determining whether the use of BIM resulted in greater adoption of RwHTS, and if so, how designers specifically use BIM to enhance acceptance of RwHTS. The question was answered by comparing the responses and the process maps generated from the two categories of respondents. Differences in process maps were observed by overlapping the process maps over each other and observing whether there were major differences that could explain how BIM altered the design process of a facility. If there were any major differences then it indicated that BIM altered the way designers designed a facility. For the second questions, the respondents were asked directly if BIM resulted in frequent adoption of RwHTS. Initially, a moderate relationship was identified at the end of the survey phase and it was tested by interviewing the respondents. Chapter 3 and 5 discusses the details of the results in greater detail.

For the pile sort, each respondent had one opportunity, unless they requested otherwise, to map the factor against the attribute by sorting the card into the associated attribute's pile. In this case each mapping was considered as a single vote to select an attribute. In such a selection process, a plurality method emerged as the best fit in comparison to a pairwise method to conduct the analysis of the data. Hence, the plurality approach was used to obtain a consensus among the pile sort for each of the two categories. The plurality method is used as a means of ranking options where a candidate with the most first place votes wins (PBS 2013). In this case, instead of candidate, an attribute was ranked. For each factor there were three votes casted by the three respondents from each category, mapping it with the attribute of innovation. Based on the vote count, whichever attribute received the maximum votes had that particular factor associated with it. In case of a tie, both tying attributes were associated with the factor. The outcome of this process was that factors associated with the adoption of RwHTS were mapped with the innovation attributes separately for the two groups (+RwHTS+BIM) and (+RwHTS-BIM).

After completing the pile sort, the data derived from quick sort was analyzed. In this case again the two categories (+RwHTS+BIM and +RwHTS-BIM) were analyzed separately. Rankings conducted by each respondent within each category were analyzed in terms of mean, median, and the spread between the data points to identify the factors which were perceived to be important for the adoption of the RwHTS by the two categories of the respondents. By the end of this process, factors associated with the adoption of RwHTS were identified for the two groups namely (+RwHTS+BIM) and (+RwHTS-BIM), as per the importance provided by the respondents.

Chapter 3: Implementation trends for Rainwater Harvesting Technologies and Strategies (RwHTS) and Building Information Modeling (BIM) in the Southeastern United States

3.1 Abstract

In the last decade, various regions around the world have faced severe problems fulfilling the needs for freshwater consumption, due to numerous factors. Researchers have also predicted that increases in current societal requirements for water consumption may cause irreparable damage to ecosystems and aquifer reserves of the planet. The sustainable science community has also realized that the outcomes of the prediction and control method have not met expectations due to various dynamic factors, thereby causing the need for decentralized systems such as rainwater harvesting. Implementation/adoption of Rainwater Harvesting Technologies and Strategies (RwHTS) reduces the consumption of freshwater within a facility as well as controls the storm water runoff. It is also one of the many ways that a facility can reach the goal of net zero resource consumption. However, adoption/implementation of RwHTS can become complex quickly due to multiple factors associated with the building. It has been accepted that the Building Information Modeling (BIM) possesses inherent capabilities to reduce complexity of such systems. The main aim of this study was to characterize the implementation trends for Rainwater Harvesting Technologies and Strategies (RwHTS) and Building Information Modeling (BIM) by architectural firms in facilities constructed between the periods of 2000-2010 in the southeastern United States. In addition, the study also tested the hypotheses that visualization, one of many functions of BIM, would be most adopted by the adopters of BIM, implementation of RWHTS is related to firm's experience with federal projects, and passive RwHTS would be adopted more than active RwHTS. The study further identified the most and the least commonly implemented RwHTS by the architectural firms included in a survey of 2,000 registered architects in Georgia, North Carolina, South Carolina, Florida, Virginia, Maryland, and the District of Columbia. Additionally, the study also analyzed the relationship between the implementation of RwHTS and BIM from the perspectives of architects. Furthermore the study also identified relationship between RwHTS/BIM with certain firm demographics. The study identified the least and most adopted RwHTS along with the functions of BIM. Future research includes further investigation into the attributes of innovations that have been implemented successfully versus those that were rejected.

3.2 Introduction and Background

97.5% of the water on earth is saline and only 2.5% is fresh and usable, out of which, nearly two-thirds is frozen in glaciers and polar ice-caps (Abaje et al. 2009). Even in such limited availability, water is still an important source for the continuation of many industries varying from agriculture, energy production, manufacturing, construction, sustenance of society, and others (Gleick 1998; Pacific Institute 2009; Postel 2000; USGS 2005). Researchers have estimated that public water supply needs have been increasing constantly since 1950 (USGS 2005). Water is already over-appropriated in many regions of the world, and droughts have been observed in various parts of continents such as Asia, Africa, Australia, and North America (Pacific Institute 2009; Postel 2000). More than one-third of the world's population, approximately 2.4 billion people, live in water-stressed countries, and by 2025 the number is expected to rise to two-thirds (Pacific Institute 2009). Furthermore, researchers have also predicted that increases in current societal requirements of water consumption can cause irreparable damage to ecosystems and aquifer reserves of the planet (Covich 1993; Gleick 1993; Postel and Carpenter 1997; Postel 2000; WWF 2012). The United States Geological Survey (USGS) estimated that about 410 billion gallons of groundwater was withdrawn per day (USGS 2005) and nearly 50% of the population in the United States depended on groundwater for their direct needs (Power and Schepers 1989). Considering the dependency of society on water resources, Barnett and Pierce (2008) further added that major reservoirs in the central United States such as Lake Mead and Lake Powell have a 50% probability of drying up by 2021, if no changes in water allocation are made. These lakes are major suppliers of water and provide economic continuity in many states (Earth Observatory 2003). Even in other parts of the United States where there is no dearth of rainfall, abundance of impervious surfaces reduce percolation of storm water into the soil and recharge of groundwater levels, thereby increasing the threat of flooding. Storm water is subsequently discharged to streams and rivers as a reactive measure, which further degrades the hydrosphere by causing problems such as increased water quality impairment, flooding, and sedimentation and loss of habitat and aesthetic value in coastal resources (Massachusetts Office of Coastal Zone Management 2000).

3.2.1 Rainwater Harvesting Technologies and Strategies (RwHTS)

Harvesting rainwater locally through various technologies and strategies can be one of the major solutions to meet this ever-increasing demand on an individual and societal basis (Angrill et. al 2011; Athavale 2003; Ibraimo and Munguambe 2007; White 2007). Multiple researchers across the globe concur that conserving rainwater through various technologies and strategies is one of the best methods to solve the serious situation of increasing water demand (Jothiprakash and Sathe 2009; Partzsch 2009). Water resources in many countries across the globe have been considered as a public resource (Sultana 2007). Within the United States over the past few years, many states have begun permitting the implementation of Rainwater Harvesting. National Conference for State Legislations (NCLS), a bipartisan organization which provides research and technical support to the policymakers also mentions that over the last 5 years there has been increased clarity on ways RwHTS can be utilized within the country (NCSL 2012).

Lately, Rainwater Harvesting Technologies and Strategies (RwHTS) have emerged as the top contender for conservation (Mun and Han 2012) even though there is little or no concurrence regarding technologies that should be considered as innovative (Partzsch 2009). RwHTS reduce the problem of over-consumption of water resources by providing an alternate source of water, further offset the impacts of stormwater and aquifer depletion on natural ecosystems (Oweis et al. 1999; TRHEC 2006), and generate other environmental, social, and economic benefits (Krishna 2003; TRHEC 2006). Rainwater harvesting has been defined in numerous ways in literature (Arnold and Adrian 198; Levario2007; Gaston 2010). Levario(2007) defines rainwater harvesting "*as the collection of rainwater without artificial inducement"* and Gaston (2010) defines it "*as the diversion or collection of precipitation in order to utilize it for some desired purpose*." For this study, Rainwater Harvesting Technologies and Strategies (RwHTS) is defined as "*technologies/strategies used for the permanent collection of rainwater for a given facility so as to enhance the water resources of the area and avoid storm water runoff and complications associated with it on the ecosystem."* Hence, these technologies and strategies may displace the consumption of freshwater within a facility, as well as help to mitigate problems associated with storm water runoff. Rainwater harvesting is also one of the many ways that a facility can reach the goal of net zero resource consumption. Additionally, rainwater harvesting has a potential to introduce a paradigm in which stormwater is managed on-site, instead of collection and centralized treatment, thereby controlling issues at the source and providing motivation to better manage site development to avoid potential problems. Parts of Australia, East Asia, and the United States have embraced rainwater harvesting as a serious way to augment sparse and irregular water supplies (Han and Park 2007; Gaston 2010; Lancaster 2010; NCSL 2012; NRDC 2011; White 2007; White 2010).

Generally, RwHTS are segregated into two major categories (City of Bellingham 2012; City of Tucson 2009), based on the way they are designed: passive and active systems. Passive RwHTS are designed to direct water to an allocated area without storing them in temporary containment systems and they generally operate through gravitational flow. These systems do not require infrastructure such as pressurized piping, metering, pumps, or power supply to support them (City of Bellingham 2012; City of Tucson 2009; Gaston 2010). In contrast, active RwHTS are designed so that the water can be stored in containment systems and used later. These systems may not solely rely on gravitational flow for operations and may use pumps, depending on the site size, condition, climatic conditions, etc. These systems do require infrastructure such as piping, metering, pumps, power supply, and other components to support them (City of Bellingham 2012; City of Tucson 2009; Gaston 2010). Gaston (2010) and City of Bellingham (2012) point out that the costs associated with passive RwHTS are generally much less than active RwHTS. Gaston (2010) also states that since passive RwHTS are inexpensive, they are more commonly implemented. Even though RwHTS have often been addressed as a relatively simple technology/strategy (Burt and Keiru 2009; City of Bellingham 2012), depending upon the end use of conserved water and the complexity associated with project type, tank size, site, and weather, RwHTS can become complex quickly (Angrill et al. 2012; City of Bellingham 2012; Chatfield and Coombes 2007; Ibraimo and Munguambe 2007; Jothiprakash and Sathe 2009; Mun and Han 2012). Even in states where RwHTS are permitted, the end usage of water is still dependent on the type of facility (LIDC 2008). Hence, to sum up, RwHTS do have the potential to help mitigate the impacts of human society, but at the same time they can easily become complex to the end user. Such technologies which alleviate negative human impacts are often termed as green or sustainable, and they are generally recommended during the early phase of design, when the designers are actively involved with the project (WBDG 2012b). Designers are an integral part of the project team from the conceptualization to completion of projects, and generally possess the expertise in most stages associated with the design (Ku and Mills 2010; WBDG 2012b), especially in commercial projects. However, projects where technologies such as RwHTS are included to improve sustainability can be intensive, iterative, complex at times, front end loaded and inter-disciplinary in nature (Horman et al. 2006; Kashyap et al. 2003; Kobet et al. 1999; Magent 2005; Reed and Gordon 2000). Thus implementation of sustainability strategies such as RwHTS adds another layer of complexity to construction projects, which already have been considered in literature as complex (Nam and Tatum 1988). To manage the complexity of commercial projects, Building Information Modeling (BIM) is used by stakeholders, including the designers, to not only enhance the visualization of systems and materials, control the geometry of the built facility, conduct environmental, site safety, and cost analysis, but also to enhance the sustainability of built facilities (AGC 2007; Azhar et al. 2008; CRCCI 2007; Ku et al. 2008; Ku and Mills 2010).

3.2.2 Building Information Modeling (BIM)

BIM has been defined in numerous ways and Table 3.1 represents some of the ways in which it has been defined in literature by some of the important stakeholders associated with the AEC industry. The definitions mentioned in the table and identified in the literature indicate that BIM is not only utilized as a product, but also as a process to contribute towards the design process, which most of the time is iterative among the stakeholders (AGC 2007; Ku and Taibet 2011; NIBS 2007). In addition, BIM provides various design options for sustainability which can be pursued and automatically tracked in the model. Advanced visualization and computational techniques can be used for analysis of natural systems with which the built facility interacts (Strafaci 2008).

Table 3.1: Definitions of BIM in literature

Source	**Operationalization of BIM**
AGC (2007)	*"A data-rich, object-oriented, intelligent and parametric digital representation of the facility, from which views and data appropriate to various users' needs can be extracted and analyzed to generate information that can be used to make decisions and improve the process of delivering the facility."*
AIA (2007)	*"A digital three dimensional model linked to a database of project information, combining all information from the design inception to the facility management."*
Autodesk (2009)	*"An integrated process built on coordinated reliable information about a project from the design through construction and operations."*
NIBS (2007) and WBDG (2012a)	*"A digital representation of physical and functional characteristics of a facility which serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle from inception onward."*

Hence, the capabilities of BIM can be used to conduct various analyses to enhance the sustainability of the facility. Researchers have pointed out the extent to which BIM can be used with respect to achieving sustainability for a built facility, including LEED certification (Azhar et al. 2009; Sidduiqui et al. 2009). Azhar et al. (2011) further indicates that BIM can be used for calculation of water savings. Implementation of BIM for analysis can also conserve time for the engineers and designers. Luthra (2010) citing Rundall (2007) states that the BIM reduces errors for the designers during the design phase and further that the designers are the heaviest users of BIM in the US.

Contrary to the aforementioned benefits of BIM, Zhilang and Li (2008) in their work point out that there are still imperfections within BIM and designers/engineers conducting various types of system analysis for the recommended facility invested more than 50% of the time dealing with interoperability issues. Interoperability of software is a concern which has been identified by multiple researchers (McGraw-Hill

2009; Ku and Taibet 2011; Zhilang and Li 2008). Ku and Taibet (2011) during their survey among contractors found lack of interoperability to be one of the barriers impeding the implementation of BIM. Further, Barlish (2011) points out that the benefits from the implementation of BIM have not been proven. Barlish (2011) indicates that although claims have been made by professionals and researchers about the benefits of adoption of BIM, at the same time, the methodology used to conduct the analysis is being questioned. The author also questions the generalizability of the findings which indicate the positive impact of BIM.

Hence, to sum up, sustainable technologies such as RwHTS have the potential to mitigate human impacts on the environment. However, implementation of sustainability technologies in capital projects adds complexity to those projects. BIM has been identified as one of the tools that can reduce complexity of projects by enhancing visualization, collaboration, and information regarding the project. However, the benefits of BIM have been debated in the literature. Can a tool such as BIM help to facilitate greater implementation of sustainability strategies such as RwHTS through reducing complexity and enhancing visualization of these strategies?

3.3 Point of Departure

This section discusses the point of departure for this study. The departure for this study is based on analyzing the existing body of literature regarding the complexity and implementation of RwHTS. Additionally, the existing studies on the implementation of BIM from designers' perspectives are reviewed. This analysis is conducted so as to ascertain the implementation of RwHTS and BIM among designers and identify if any relationship could be identified between implementation of RwHTS and BIM.

3.3.1 Rainwater Harvesting Technologies and Strategies (RwHTS)

Studies on rainwater harvesting have depicted how RwHTS can reduce dependence on aquifer resources and contribute towards resolving the increasing societal and economic water demands across the globe (Jyothiprakash and Sathe 2009; Sivanappan 2006; Sultana 2007). At the same time, they can become complex, depending upon numerous factors such end use of conserved water, the complexity associated with project type, tank size, site, collection, transportation, and weather (Angrill et al. 2012; City of Bellingham 2012; Chatfield and Coombes 2007; Ibraimo and Munguambe 2007; Jothiprakash and Sathe 2009; Levario 2007; Mun and Han 2012). In order to reduce the complexity of green projects, BIM offers functions such as enhanced visualization, data management, and higher collaboration. These functions reduce the complexity associated with the adopted sustainable systems, by enabling the potential adopters not only the capability to view the innovation but also evaluate the performance and benefits of the innovation with regard to the facility and then share the outcomes with all the direct stakeholders of the project. BIM has been found by researchers to have the potential to positively impact the adoption of sustainable technologies (Azhar et al. 2009; Sidduiqui et al. 2009). The next section discusses the studies conducted within the realms of AEC to identify the adoption of BIM.

3.3.2 Building Information Modeling (BIM)

Numerous studies have been incorporated in the past five years to identify the BIM implementation globally by the stakeholders associated with the AEC industry. Luthra (2010) analyzed the implementation of BIM among architects, engineers, and contractors with regard to the Indian context. A survey was sent to 45 architectural firms located in India and the conclusion was based on the response of 25 architectural firms. The study found that the concept of BIM was known to the respondents with 48% of the respondents adopting BIM. The study also surveyed the perceptions of adopters about various software used and benefits of using BIM, but did not discuss the function(s) of BIM. McGraw-Hill (2009) conducted a survey to understand the implementation of BIM. The survey provided a deeper understanding for the overall implementation of BIM within the AEC industry in the U.S. For this study, a survey was sent to industry professionals which included Architects, Owners, Engineers (MEP, Civil, Structural, Environmental, Transportation, and others), Manufacturers/Distributers, Construction managers/General contractors, fabricators, and other. The survey received 2,228 complete responses and 27% of the respondents (598 in number) of the survey were architects, and the rest of the respondents of the survey were other stakeholders associated with the AEC industry such as owners, contractors, and engineers. Although the survey intensively investigated the implementation of BIM across the industry, however the study did not simultaneously investigate into implementation of sustainable strategies, including RwHTS, and the relationship between RwHTS and BIM. Another study by McGraw-Hill (2010) did investigate at the implementation of both BIM and sustainability, but was not specific in terms of the implementation of water conserving strategies such as RwHTS. The study received 494 completed responses and 31% of the respondents (153 in number) were architects. Ku and Taibet (2011) also conducted a study to analyze the implementation of BIM, using survey research design, but the target population of the study were contractors.

Based on this review, a study is deemed as required to address the current implementation patterns for RwHTS and BIM by architectural firms within the United States and identify relations between BIM and implementation of RwHTS; especially when multiple researchers have pointed out that BIM has the ability to facilitate in green building design. Furthermore, in order to understand the implementation patterns of RwHTS and BIM, current use trends in these technologies and strategies need to be identified. Further, insight is also needed regarding the characteristics of architectural firms that are innovative in their use of RwHTS and BIM. In addition, architectural firms were selected as the general population for the survey as architects/designers are involved from early stages of project feasibility to define a program, choose the site, and provide expertise with associated tasks (WBDG 2012b), and it is precisely at this phase when sustainable strategies (RwHTS in this case), along with BIM, have the potential to be considered for use on the project. This study creates a bridge between successfully implemented RwHTS/BIM on commercial projects and the characteristics of the innovative firms that chose to include these innovations in their project design.

The main aim of this study was to identify the trends for implementation of RwHTS and BIM among designers in the southeast US . In addition, the following hypotheses are tested:

- Visualization, a function of BIM, would be most adopted (McGraw-Hill 2009)
- Passive RwHTS would be adopted more than the Active RwHTS
- Implementation of BIM is related to the firm size
- Implementation of BIM is related to firm experience
- Implementation of RWHTS is related to implementation of BIM
- Implementation of RWHTS is related to firm experience
- Implementation of RWHTS is related to the firm size
- Implementation of RWHTS is related to firm's experience with federal projects

Specifically, the study seeks to answer the following questions:

- What implementation patterns are observed for RwHTS and BIM?
- How do respondents fit with respect to the four adopter categories of BIM and RwHTS?
- Which of the list of RwHTS identified in Phase I should be included in Phase II?

The next section addresses the methodological approach taken into consideration to answer the research questions.

3.4 Methodological Approach

To achieve the aims of the research, a sample of 2,000 designers located in the seven southeastern states was selected, including Georgia, North Carolina, South Carolina, Florida, Virginia, Maryland, and the District of Columbia. A survey was developed with questions targeting experiences associated with the implementation of RwHTS in built facilities over the last decade by architectural firms, along with the characteristics of the selected firms. Figure 3.1 depicts the overall methodological approach utilized for the research, including the three phases comprising the study. The three major phases were:

- Survey planning and development
- Survey implementation
- Data analysis

Each of the three stages is described in the following sections.

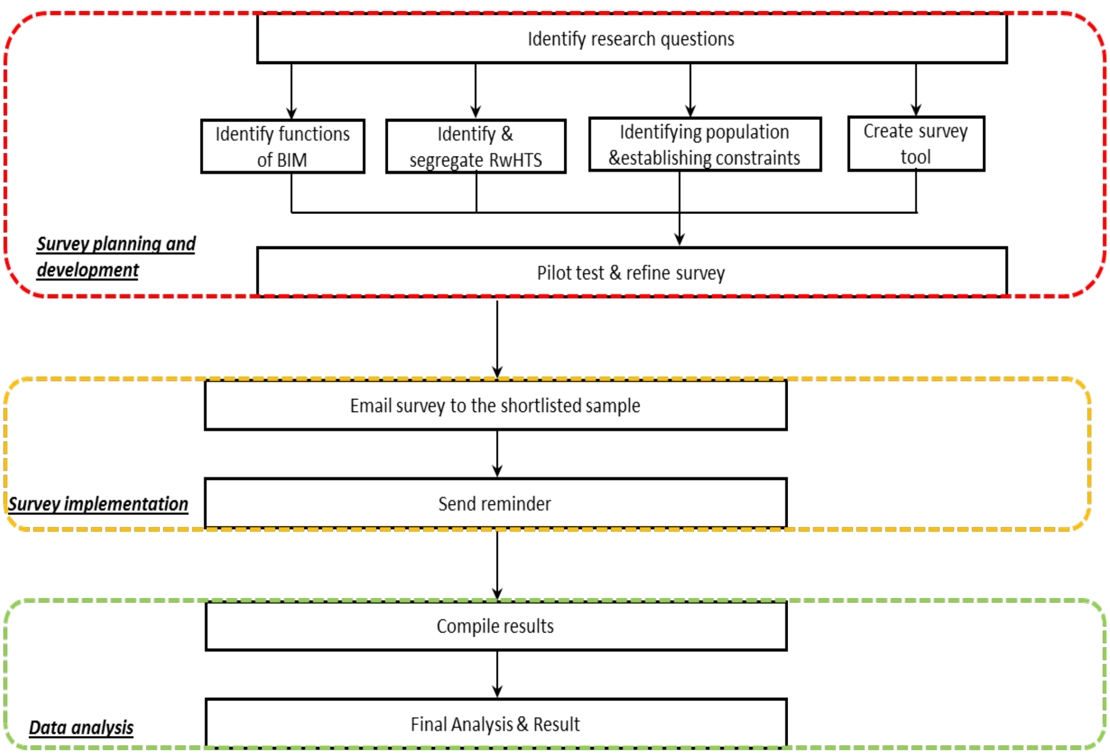


Figure 3.1: Methodological approach employed in the research

3.4.1 Survey planning and development

The first stage aimed at planning, designing, and testing the survey before it was implemented. The first step in this stage involved clarifying hypotheses and questions to be investigated in the survey. Once the set of hypotheses and questions were determined, the next step involved operationalizing and identifying RwHTS for this study. In order to identify various RwHTS, the LEED reference guide version 3.0 was used, since many federal and state agencies mandate LEED as a measuring tool to evaluate the sustainability of a building (Bossink 2004; DuBose et al. 2007; Langar 2008). Additionally, LEED is established within construction industry and widely applied in the United States (Langar 2008). Hence, the most current version at the time of study, LEED V3.0, was used to identify RwHTS. Hermeneutic methods were used for analyzing the data from the reference guide and developing descriptive definitions for the identified RwHTS. Hermeneutics methods generally cover the understanding and interpretation of linguistic and non-linguistic expressions (Ramberg and Gjesdal 2005). This method was developed from Boell and Cecez-Kecmanovic (2010). Figure 3.2 depicts the adaptation of the hermeneutic process to identify RwHTS.

Figure 3.2: Method used to identify and develop descriptive definitions for RwHTS

For this study, the sequence was completed only once and is not a continuous iterative process. The nine RwHTS identified for this study were: Above-ground rainwater storage, Bioswale, Constructed wetland, Extensive green roof, Intensive green roof, Permeable pathway, Rain garden, Retention pond, and Under-ground rainwater storage. Table 3.2 discusses the operationalization of the selected RwHTS for this study.

Table 3.2: Terms operationalized for this study

Terms	Operationalization
Rainwater Harvesting Technologies and Strategies (RwHTS)	*The technologies/strategies used for the permanent collection of rainwater within a given facility so as to enhance the water resources of the area and avoid storm water runoff and complications associated with it on the ecosystem.*
Active RwHTS	*RwHTS that are designed so that the water can be stored in containment systems to be used later, may not solely rely on gravitational flow for operations, and may use pumps. These systems may require infrastructure such as piping, metering, pumps, and other components to support them.*
Passive RwHTS	*RwHTS that direct water to an allocated area for infiltration into the ground and generally operate through gravitational flow. These systems do not require any infrastructure such as pressurized piping, metering, or pumps, to support them.*
Above-ground rainwater storage	*The process in which water is filtered and sequestered into rainwater tanks and released as per the requirements of the end-user. These tanks are located above the ground surface and can be designed to be visible to provide a medium for educating the users and visitors to the facility about the RwHTS.*
Bioswale	*Natural gradation is achieved to partially treat rainwater quality, naturally retain the water on-site, and weaken the potential of flooding.*
Constructed wetland	*A mechanism for the conservation and purification of water and also a means to revive the natural ecosystem that was in place before the facility was built.*
Extensive green roof	*A layered roof that is less than six inches in depth and is designed to satisfy specific engineering and performance goals of reducing storm water runoff and the urban heat island effect.*
Intensive green roof	*A layered roof that is equal to or more than six inches in depth and is designed to satisfy specific engineering and performance goals of reducing storm water runoff and the urban heat island effect, as well as providing habitat for avian species.*

Permeable pathway	*Pathway that allows the water to infiltrate through it by having voids in it so as to minimize the storm water runoff and recharge the groundwater table.*
Rain garden	*Shallow gardens which have two to eighteen inches of depressions, typically planted with native plants, strategically located to collect, infiltrate, and filter rain to minimize storm water runoff and recharge the groundwater table.*
Retention pond	*Ponds that are designed to hold water indefinitely and at times release the water at flow rate that mimics the natural condition.*
Under-ground rainwater storage	*A tank or cistern under the ground into which rainwater is channelized, filtered, sequestered and then released as per the requirements of the end-user.*
Green Building	*A building that reduces the consumption of natural resources in an efficient manner. It does not necessarily need to be certified by any of the existing measurement tools established by LEED, NAHB green standard, Green Globe, or others.*

In addition, literature identifies two major categories of RwHTS based on the way they are designed: passive and active systems (City of Bellingham 2012; City of Tucson 2009). Based on the definitions established for active and passive RwHTS, all nine RwHTS were analyzed in terms of the individual descriptive definition, requirements to install and operate. Based on analysis of RwHTS, the nine RwHTS were classified as either active or passive RwHTS. Table 3.3 discusses segregation of the selected RwHTS, based on operationalization of the terms. Upon completion of this sort, it was subjected to expert review to further refine and validate the sort.

Table 3.3: Segregation of the selected RwHTS

Active RwHTS	**Passive RwHTS**
Above-ground rainwater storage Extensive green roof Intensive green roof Under-ground rainwater storage	Bioswale Constructed wetland Permeable pathway Rain garden Retention pond

After identifying and classifying the RwHTS, the next step involved establishing the functions of BIM to determine how it was being used by target firms. For BIM, seventeen different functions were established for which it could be used by contractors in the AEC industry (Ku and Taibet 2011), although no studies have specifically identified roles for how BIM could be used in design. Further expanding on the works of Taibet and Ku (2011), in which the functions of BIM relevant for contractors was identified, a list of comparable functions relevant to architects were identified and further developed with an expert professional from the industry. Identified design-phase functions include: *clash detection, constructability, construction drawings, database information management, design of complex structures, estimation, facility management, initial presentations, interior environmental analysis, LEED, municipal code, parametric design, performance optimization, site analysis, restoration and renovation, sustainable design, value engineering, and visualization*. In total, eighteen functions associated with BIM relevant to architects were identified.

The general population for this study was architectural firms operating in the United States. Designers within architectural firms are responsible for coordinating various stakeholders during the design phase of capital projects. Designers have the "*legal obligations and comprehensive training in holistic problem-solving, and an understanding of broad cultural concerns which makes architects suited for the leadership of design teams (WBDG 2012b).*"

Architects/designers are involved from early stages of project feasibility to help define a program, choose the site, and provide expertise with associated tasks (WBDG 2012b), and it is precisely at this phase when sustainable strategies on a broad level are identified. Although there are numerous professional associations for registered architects, the American Institute of Architects (AIA) has been the leading professional membership association for licensed architects, with a comprehensive database of architects practicing in the United States (AIA 2012b). Hence for this study, membership in AIA by registered architectural firms was the first constraint established, for the selection of the sample.

The second constraint was the geographic location of the architectural firms. Firms geographically located in the seven states which included Georgia, North Carolina, South Carolina, Florida, Virginia, Maryland, and the District of Columbia were selected to be a part of the sample. On average, the selected states at a macro level receive nearly same amount of precipitation, which is about 40-60 inches annually (WRCC 2012). In addition to the similarity in precipitation, the selected states also represented the hot humid and mixed humid zones. These zones have been defined by PNNL and ORNL (2010) in their study and have climatic similarities in comparison to other climate zones which occur in the United States.

Hence, to sum it up, the following two constraints were established for the selection of the sample:

- The architectural firms selected must be registered with AIA
- The architectural firms selected must be geographically located in one of the seven states which fall along the southeast coast of the United States. The seven states included Georgia, North Carolina, South Carolina, Florida, Virginia, Maryland, and the District of Columbia

Once the constraints were established, it led to identification of the sample from the population of all architectural firms. After identifying RwHTS, functions of BIM, establishing constraints and selecting the sample from the larger population, the survey tool was created. A web based survey methodology was utilized because it has the ability to collect detailed, comparable from large number of individuals and enable established generalizability of information (Werner 2004). Of the many methods available to conduct the survey, for this study, emailing invitations to participants in a web-based survey was chosen because of the following major factors highlighted in literature:

- Most of the general population in the United States has access to the internet (Sheehan 2001). As a professional AEC industry segment, the target population is even more likely than the population at large to have internet access.
- Emailing invitations to participate in an online survey generates rapid response (Flaherty et al. 1998).
- The method allowed awareness of the number of emails undelivered to the sample by the researcher (Sheehan 2001).
- Value obtained by emailing a survey outweighed other methods, especially with respect to cost (Dillman 2007).

Once the survey tool and the sample for the study were finalized, the survey was pilot tested. The sample for the pilot test was architectural firms which were selected on the basis of previous working relationships. Hence, for this study, the pilot survey was sent out to ten architectural firms and two weeks were provided for their feedback. One reminder was sent upon the end of the two week period. At the end of the pilot study, a 60% response rate was received. The output of this task was a refined survey ready for implementation, which fed into the next stage: conducting the survey with the identified sample.

3.4.2 Survey implementation

Once the survey tool was designed and pilot tested, the next stage involved inviting the sample of architectural firms to participate. Two variables were consistently identified in literature which were relevant for this step and affected the response rates for the studies analyzed. The two variables were "*pre-notification*" and "*follow-up*" of the survey (Sheehan 2001). For this study, the respondents were not pre-notified. However, a cover letter was sent as an email, which included an abstract about the study and a link to the survey. The cover letter was personalized to individual participants in order to achieve a higher response rate. Respondents were offered the opportunity to have the aggregated results shared with them without revealing individual responses. Six weeks after the initial email, a reminder was sent to the firms which had not responded to the survey or had partially completed the survey. Literature indicates that the response rate increases up to 40% (Comer and Kelly 1982; Murphy et al. 1990) by sending a reminder. Specifically in email surveys, Sheehan and Hoy (1997) found that the follow-up increased the response rate by 25%. For this study, the total number of responses increased by about 45% after the first reminder, which aligns with what has been observed in the literature. For this study, only one reminder was sent. After four weeks from the first reminder, the survey was closed. The results of the survey then fed into the next step: compiling all the information and analyzing it, so that the objectives outlined prior to beginning of this phase could be accomplished.

3.4.3 Data analysis

The last stage aimed at compiling and analyzing all the information collected from this process. The aim was that all the information compiled and analyzed would be able to test all the identified hypotheses and answer all the questions discussed in the subsequent section. All the survey responses were downloaded from the website in spreadsheet form and the results were compiled. At a generalized level, it was observed that the response rate for the survey was about 19%. However, upon closer inspection of the responses it was found that 4% of the respondents had not completed the survey, in regards to the questions asked. Accordingly, the effective response rate came down to about 15%. Sheehan (2001) points out in his study that a high response rate on an internet-based survey is difficult to obtain due to numerous factors such as increased internet sampling by investigators, information overload on the respondents, compensation of time, and others. With these factors the calculated percentage of 15% was accepted. Once all the data were captured in an excel spreadsheet, descriptive statistics were developed along with generating a relationship between implementation of BIM and RwHTS. In order to test the relationship between BIM and RwHTS, the Chi Square Test was used. Chi Square Test is appropriate when the population is at least ten times as large as the respective sample, which was the case in this study. There are two types of Chi Square Test, namely Chi Square Test of Goodness of Fit and Chi Square Test of Independence. Of the two, Chi Square Test of Independence was used, since the two categorical variables (use of RwHTS and use of BIM) were with reference to a single population. In addition the test of independence was used to determine if a significant association between the two variables could be established. It was used to prove/establish a relationship between the data collected and the hypotheses to be tested. Data analysis sought to answer the following questions:

- Is there any relation between the implementation of BIM and RwHTS with architectural firm characteristics such as the size of the firm and experience of the firm in the market?
- Is there any relation between the implementation of RwHTS and BIM by individual firms?

However, Chi Square Test can only prove/disprove a relationship between variables. In order to test the strength of a relationship, Cramer's V test was used. Cramer's V is a measure of the strength of relationship and measures the degree of association between the values of the row and column variables on a scale of 0 to 1 as depicted in Table 3.4.

Table 3.4: Relation of Cramer's V with the strength of relation (Texas Tech University 2013)

Value of Cramer's V	**Strength of relationship**
0.80 or 1	Very Strong relationship
0.60-0.80	Strong relationship
0.40-0.60	Relatively strong relationship
0.20-0.40	Moderate relationship
0.10-0.20	Weak relationship
0.00-0.10	Negligible relationship

Apart from hypotheses testing, a generalized descriptive statistical analysis was conducted to address the following set of hypotheses and questions, which were identified at the beginning of the research:

- Visualization, a function of BIM, would be most adopted
- Passive RwHTS would be adopted more than the Active RwHTS
- Implementation of BIM is related to the size of the firm
- Implementation of BIM is related to firm experience
- Implementation of RWHTS is related to implementation of BIM
- Implementation of RWHTS is related to firm experience
- Implementation of RWHTS is related to the firm size
- Implementation of RWHTS is related to firm's experience with federal projects

Additionally, the study seeks to answer the following questions:

- What implementation patterns are observed for RwHTS and BIM?
- How do respondents fit with respect to the four adopter categories of BIM and RwHTS?
- Which of the list of RwHTS identified in Phase I should be included in Phase II?

The next section discusses the results for the hypotheses tested and questions in greater detail.

3.5 Results

For this study, the survey was emailed to approximately 2,000 architectural firms, geographically spread across seven states in the southeast coast of the United States. However, approximately 15% of the architectural firms emailed did not receive the survey due to the following factors:

- Change of email address
- They were no longer in business due to various reasons
- The firewall settings of the architectural firms did not allow the survey to be delivered and as such caused a delivery failure.

These factors were anticipated from the very beginning as they had been pointed out in the literature (Bradley 1999). After conducting the necessary deductions for members of the sample that did not receive the survey, for this study the research team considered 1,700 as the sample size. It was also found that 4% of the respondents had not completed the survey properly, in regards to the questions asked and effective response rate was about 15%.

3.5.1 Survey demographics

This section discusses the demographics of the respondents of the survey. Figure 3.3, 3.4, and 3.5 represent the geographic location, firm size, and firm experience of respondents.

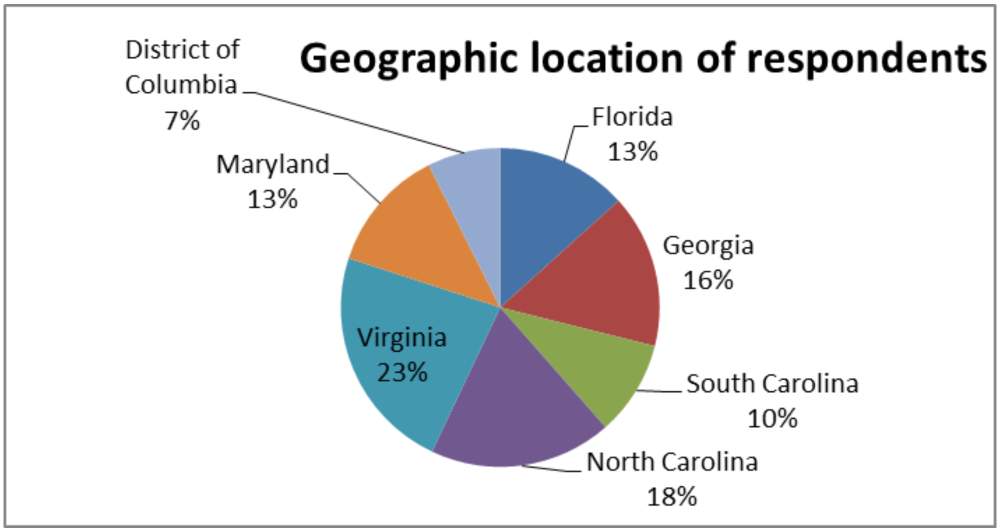


Figure 3.3: Geographic location of respondents (state in which main office is located)

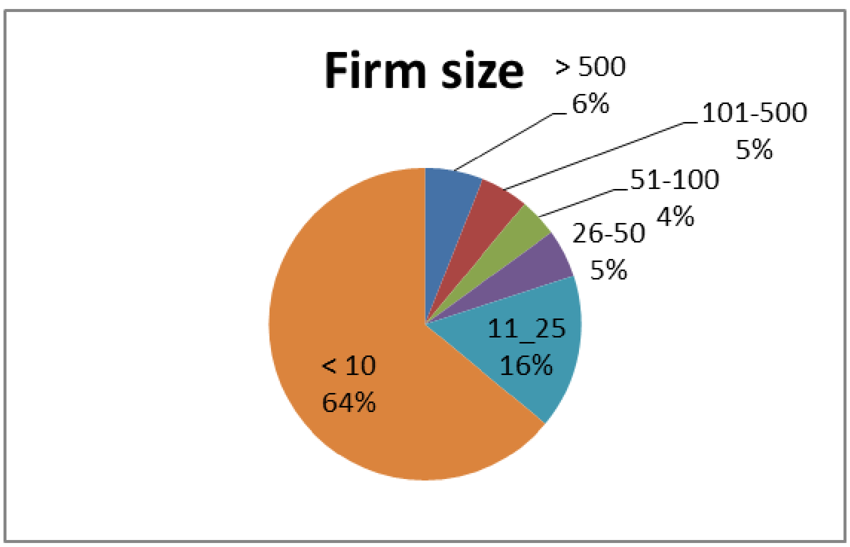


Figure 3.4: Firm size of respondents (number of employees)

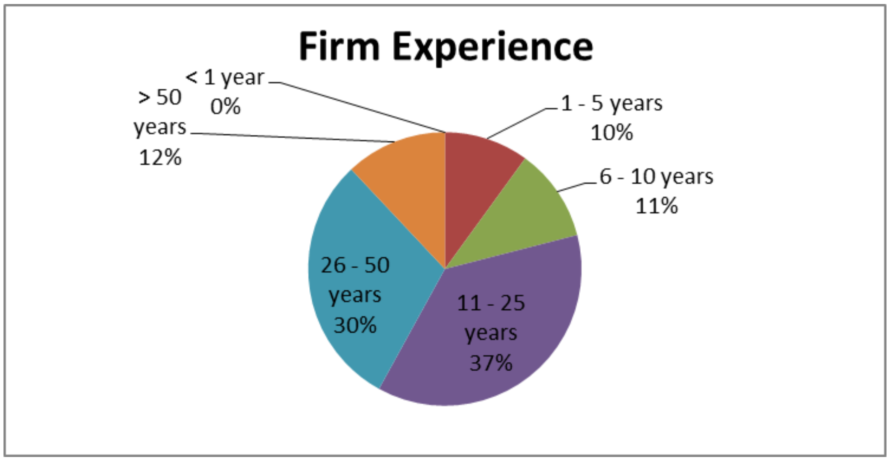


Figure 3.5: Experience of respondents (years)

These demographics were compared with a national survey conducted by AIA in 2009 of approximately 2700 architectural firms. Multiple parallels were drawn between the demographics of the survey conducted by AIA (2009 and 2012) and the demographics of this survey and they are as following:

- Firstly, all the three surveys found that small architectural/design firms (less than 10 employees) form a major part of the AEC industry.
- Secondly, as per AIA (2009 and 2012), medium design firms (10-99 employees) formed 17% and 18% of the overall survey respectively, and for this study formed 22% of the total respondents.
- Thirdly, large design firms (100 or more employees) form a small part of the whole AEC industry. As per AIA (2009 and 2012), firms with more than 100 employees formed 2% and 1% of the overall survey respectively, and for this study formed 4.12% of the total respondents.

Hence, multiple close parallels were derived between this survey and the survey conducted by AIA in 2009 and 2012 to establish the generalizability of the study. This also suggests that the respondents for this survey are representative of the design industry.

After this initial analysis, the responses were analyzed in terms of responses for green buildings. 69% of the survey respondents indicated that they had designed Green building(s) from 2000-2010. Of those respondents, about 9.4% had never incorporated any RwHTS for the designed green buildings, 1.10% had used all of the nine RwHTS mentioned in the survey, and 32.50% had used more than half of the mentioned RwHTS. The next section discusses the RwHTS implementation as per the responses provided by the respondents of the survey.

3.5.2 Trends for implementation of RwHTS and BIM

The subsequent section discusses the trends that were observed for the implementation of RwHTS and BIM, along with identifying the relationship observed with the implementation of RwHTS and BIM with firm size and firm experience.

3.5.2a RwHTS Implementation

A further analysis of the survey revealed retention ponds to be the most commonly implemented RwHTS by the respondents. 53% of the respondents indicated that they had included this strategy on one or more projects between 2000-2010. The study also found the intensive green roof to be the least commonly implemented RwHTS, with 8% of the respondents indicating that they had implemented it from 2000-2010. Figure 3.6 shows the degree to which respondents had implemented each of the nine RwHTS on at least one project during the study period. As observed in figure 3.6, passive RwHTS had been implemented by more of the respondents from 2000-2010 than the active RwHTS, with three of the top five RwHTS being passive. All of the RwHTS in this study had been implemented to some degree by respondents during the study period, implying that architects realized the importance of RwHTS in meeting building design goals. However, the data indicated that respondents have preference in employing some more frequently than others and do not implement them uniformly as depicted in Figures 3.6. In fact, only a few firms - about 1.10% of the respondents - answered that they had implemented *all* the RwHTS mentioned in the study.

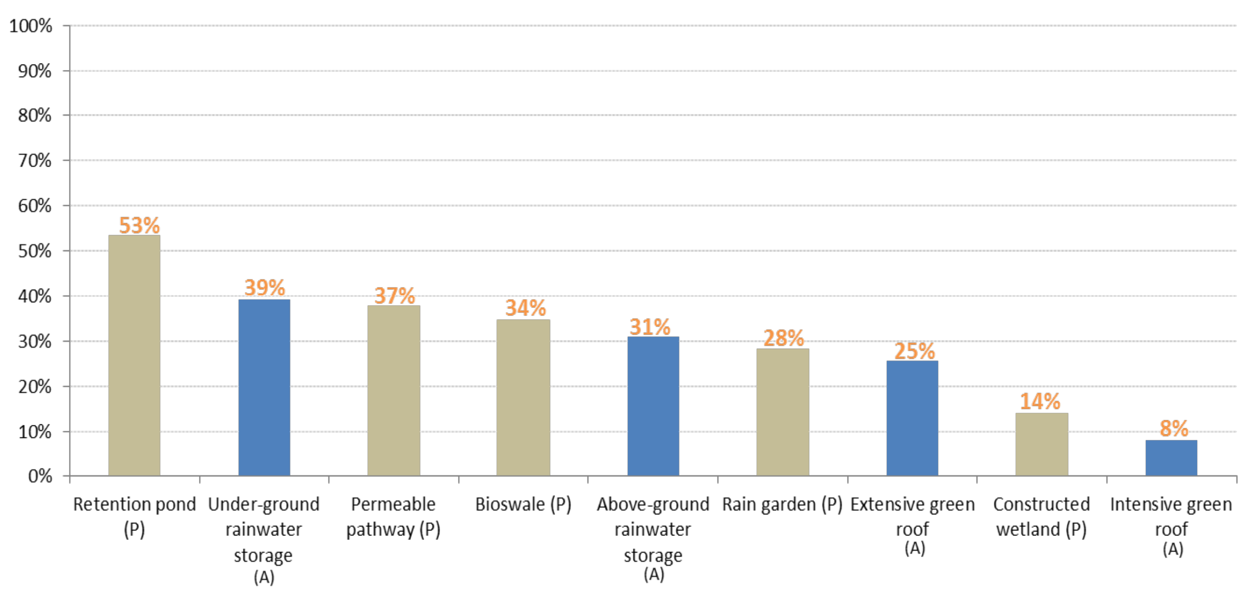


Figure 3.6: Implementation of various RwHTS by designers (P: Passive RwHTS; A: Active RwHTS)

The next section discusses the BIM implementation as per the responses provided by the respondents of the survey.

3.5.2b BIM Implementation

After analyzing the responses related to RwHTS, the responses for the implementation of BIM were analyzed. Figures 3.7 depicts the functions that had been adopted on at least one project by the responding firms, based on the responses proved in the survey. Of the 18 functions identified, visualization followed by initial presentation was most commonly used. Facility management and Municipal code compliance, identified as functions of BIM, were least commonly adopted by the responding designers. Hence, supporting the hypothesis that Visualization, a function of BIM, would be most adopted.

During the course of statistical analysis, the percentage of adopters of BIM+RwHTS was calculated. It was found that nearly 77% of respondents of the survey were adopters of at least one RwHTS on at least one project, and 40% of the respondents were adopters of at least one BIM function on at least one project. In addition to the above results, the study also tested the following hypotheses which has been discussed in table 3.5

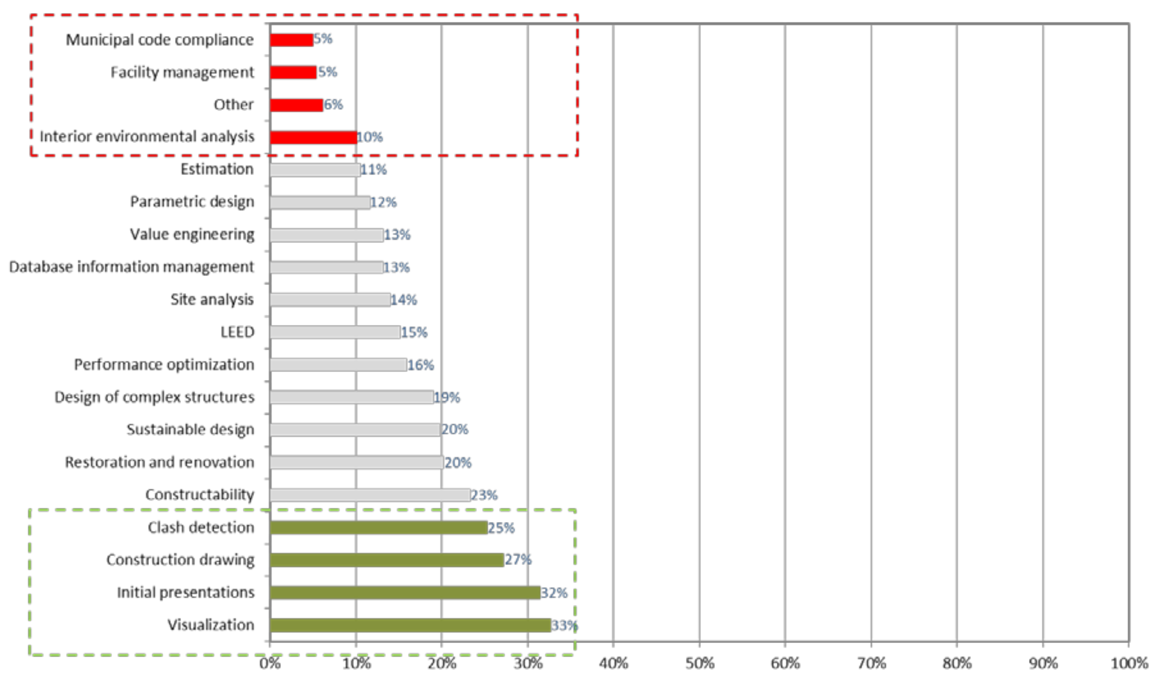


Figure 3.7: Implementation of various functions of BIM by designers

The above mentioned hypotheses were tested to answer the following questions:

- Is there any relation between the implementation of BIM/RwHTS with architectural firms' characteristics such as the size of the firm and experience of the firm in the market?
- Is there any relation between the implementation of RwHTS and BIM?

The above mentioned results from the Chi Square Test of Independence and Cramer's V test help answer these questions.

Table 3.5: Strength of relationship between BIM/RwHTS and respondent characteristics

Sr. No.	**Hypotheses**	**Chi Square Test Value**	**Cramer's V Value**	**Existence of relationship**	**Strength of relationship**
1	Implementation of BIM is related to the firm size	55.01	0.48	Yes	Relatively strong
2	Implementation of BIM is related to firm experience	11.83	0.22	Yes	Moderate
3	Implementation of RwHTS is related to implementation of BIM	16.28	0.25	Yes	Moderate
4	Implementation of RwHTS is related to firm experience	7.41	0.16	Yes	Weak
5	Implementation of RwHTS is related to the firm size	169.26	0.81	Yes	Very Strong
6	Implementation of RWHTS is related to firm's experience with federal projects	1.21	N/A	No	None

3.5.2c BIM/RwHTS Implementation with firm size

Based on the values generated of Cramer's V, it can be implied that the size of firm has a significant relationship with the Implementation of innovation (BIM and RwHTS) than firm experience. In addition, the relationship between firm size and RwHTS Implementation was stronger than BIM implementation (0.80 vs. 0.48). Hence, the firm size is a more important factor to consider for implementation than firm experience in the industry.

3.5.2d BIM/RwHTS Implementation with firm experience

In addition, relationship between BIM and firm experience was found to be significant between RwHTS and firm experience (0.22 vs. 0.16). BIM and firm experience shared a moderate relationship whereas RwHTS implementation shared a weak relationship. From this analysis, it can be stated firm experience has a very moderate relationship with BIM/RwHTS implementation

3.5.2e RwHTS implementation with experience with federal projects

This hypothesis was rejected while calculating the Chi Square Test implying that no such relationship existed between the implementation of RwHTS by an architectural firm and its previous experience with federal projects, where resource efficient buildings have become a requirement.

3.5.2e Implementation RwHTS with BIM

A moderate relationship was observed between the implementation of RwHTS and BIM (0.25). It is a possibility that adopters of BIM and RwHTS are adopting these innovations because of their inherent nature. And this very inherent nature was causing the implementation. This relationship will be further investigated in future research by conducting interviews with architectural firms.

3.6 Limitations and future research

The respondents of the study were designers/architects geographically located along southeast coast of the United States. Based on consistency of the sample demographics with the demographics of the overall population of firms identified in a national study by AIA (2009 and 2012), one can argue for the generalizability of the findings from the study.

This study also found that passive RwHTS are adopted more than active RwHTS. However, the design of the study did not establish the reasons that underlie the difference, since the process/reasons of implementation was outside the scope of the survey. A future study could explore the factors that encourage or discourage implementation. Additionally investigations need to be conducted to ascertain why there is a disparity between the implementation of retention ponds, which tend to have lower impact on the environment than other strategies. Investigation needs to ascertain whether the design industry is moving toward implementation of natural systems. Such systems not only interact with the human designed environment such as buildings, structures, and others, but also have a lower impact upon the place where they are implemented in comparison to the conventional strategies.

Retention ponds were reported to be adopted by 53% of the respondents followed by under-ground rainwater storage with 39% of respondents adopting it. In addition, a huge disparity existed between implementation of the two types of green roofs. Extensive green roofs had been adopted by 25% of the respondents and intensive green roofs was adopted by 8% of the respondents, which is nearly one-third. A similar relationship was observed between the underground rainwater storage and above ground rainwater tanks, where the former is adopted by 39% respondents and the latter by 31% adopters. This difference is still less than the one observed between the two types of green roofs. A more detailed study of implementation factors would help to explain these findings and ascertain if factors such as cost, complexity, operations and maintenance of systems play a role during the implementation process, as identified in literature.

The study found that design firms used BIM least for municipal compliance and facility management. The reason for lower use in municipal compliance can be attributed to the reason that either officials do not require electronic submissions from design firm(s) or interoperability issues exists between the software used by the design firm(s) and municipal office. In addition, from the results there is also an indication that the benefits of creating BIM model are not presently transferred by the designer to the owner. However this is just an assumption based on the response received. A counter argument for the lower use of model for facility management can be that the contractors at times acts as model coordinator prior to and during construction and updates the model upon completion of project. And upon completion of the project the model is submitted to the owner by the contractor. However future investigations need to be conducted in the both areas to identify:

- Firstly, are the municipal offices across the nation capable enough to handle such models so that these are not the barriers and can pave way for a global exchange of information
- Secondly, are the benefits of creating a BIM model transferred to owner on a general basis? Additionally a BIM model can provide numerous benefits to the owners/facility managers over the lifecycle of the facility, although barriers exist to effective use of BIM by owners, including training of facility managers, lack of previous experience, initial cost associated for the purchase of necessary software and hardware, maintenance of the model, and others. This aspect demands more detailed investigation, including identification of factors that act as barriers for the use of models for the purpose of facility management.

Furthermore, as per the responses to the survey, the study also found that not all functions of BIM and types of RwHTS had been adopted by individual firms. This result is not surprising for RwHTS, since implementation of specific RwHTS technologies is in response to owner desired and site conditions. However, for BIM, it poses an important question: is BIM underutilized by the designers, provided it is aimed for data integration and management apart from enhancing visualization? Are most adopters (designers in this case) currently aiming for the lowest hanging fruit?

3.7 Contributions

This section identifies contributions made to the existing body of literature, as follows:

- Passive RwHTS are adopted more than Active RwHTS.
- The study identified types of RwHTS and functions of BIM that had been adopted on at least one project by the responding population, thereby informing prospective adopters about the choices made by designers.
- The number of firms reporting having adopted at least one feature of BIM was lower than the number of firms reporting implementation of at least one type of RwHTS.
- The study found a moderate relation between the implementation of BIM and RwHTS.
- The study also found that firm size has a stronger relationship with the implementation of innovation (BIM and RwHTS) than the firm experience.

Chapter 4: Attributes of innovation affecting the adoption of Rainwater Harvesting Technologies and Strategies (RwHTS)

4.1 Abstract

Innovation has been defined as any practice or material artifact perceived to be new to the relevant adopting unit. The success of an innovation within the society is gauged by its adoption and the rate at which it diffuses within the society. Five attributes of an innovation described in the literature explain different rates for adoption of an innovation, including relative advantage, compatibility, complexity, observability, and trialability. Of these, observability was studied in this research and it is identified to be positively related to the adoption of innovation. This study aimed to identify the industry-identified factors that contributed towards adoption of the selected RwHTS and map those factors upon the attributes of innovation. The selected RwHTS were extensive and intensive green roofs, permeable pathways, and underground and above-ground rainwater storage tanks. The study also ascertained which attributes of innovation were perceived to be important for the adoption of RwHTS and determine whether observability stood out as more frequently identified than the rest of the attributes. For this study, three design firms representing the categories (+RwHTS+BIM and +RwHTS-BIM) were used as the unit of analysis. These firms were purposively selected from the available set of respondents to an earlier survey of design firms. Pile and quick sort, along with interviews, were utilized as the chosen methods to derive data. Upon completion of data collection, the data was statistically analyzed to observe the results for this study. The study identified factors perceived to be important towards the adoption of RwHTS for the respondents representing the two different categories (+RwHTS+BIM and +RwHTS-BIM). The study found that that observability was less important than other attributes in the adoption decision. Compatibility and relative advantage were found to be more important in affecting the adoption of RwHTS for the respondents representing the two categories (+RwHTS+BIM and +RwHTS-BIM). The study also identified that use of BIM enhances trialability.

4.2 Introduction and Background

The built environment has been linked to a variety of negative impacts that threaten to affect the survival and prosperity of the human race (Keysar and Pearce 2007; Kibert et al. 2007; SOE 2011; WWF 2012). Buildings across the United States are significant consumers of limited non-renewable resources to fulfill their demands during construction and lifecycle (Watson 1979; OFEE 2003; Keysar and Pearce 2007; Randolph and Masters 2008; McCoy et. al 2012). This unabated consumption of resources, combined with the growing population, is altering the capabilities of the planet to absorb the wastes generated and fulfill human needs for natural resources. The Architecture Engineering and Construction (AEC) industry, while serving its purpose, has severely impacted the health of the environment and depleted the natural resources (Vanegas 2003). These changes both at an individual and societal level are affecting the ecosystems within which we live, and thereby making them more fragile (WWF 2012). To mitigate the ill-effects of buildings on the environment, the phenomenon of sustainability will be one of the prime wedges that can offset or mitigate the ill-effects of the built environment (Randolph and Masters 2008).

In order to align the direction of the AEC industry towards the concept of sustainability, development of sustainable innovations is crucial, as pointed out by Rennings (2000). Vanegas (2003) further points out that adoption of sustainable innovations is required as the society cannot continue to conduct business as usual. The use of innovations by the AEC industry is not new, although various studies in literature have depicted that this industry in the United States has not been actively adopting innovations (Dewick and Miozzo 2004; Matar et al. 2008; Mitropoulos and Tatum 1999) due to numerous factors (Koebel 1999; McCoy et al. 2012). Multiple researchers have stressed the need to facilitate innovation in construction because of many factors such as complexity of projects, challenges posed by projects, unique demands of the projects Nam and Tatum 1992; Park et al. 2004; Slaughter 1998), and the manner in which the AEC industry is impacting natural resources (Keysar and Pearce 2007; Kibert et al. 2007; SOE 2011; Vanegas 2003; WWF 2012).

Many innovations aimed toward sustainability appear to incrementally improve existing ideas and practices (Hines and Marin 2004). Hellstrom (2007) citing the work of Rennings (2000) defines sustainable innovation or eco-innovation as "*the process of developing new ideas, behavior, products, and processes that contribute to a reduction in environmental burdens or to achieving ecologically specified sustainable targets*." Such innovations at times can be incremental or radical in nature depending on what they are replacing, the availability of the technology, and other contextual factors. In regard to sustainable innovations, this study focused on Rainwater Harvesting Technologies and Strategies (RwHTS), as these technologies/strategies enable society to meet the ever increasing demands for water resources by conserving rainwater and reducing the impacts of storm water runoff at an individual project and overall societal basis (Athavale 2003; Hellstrom 2007; Ibraimo and Munguambe 2007; Rennings 2000). RwHTS also generate additional sources of water, thus helping to mitigate the problem of over-consumption of water resources and further offset the impact of human development on ecosystems (Oweis et al. 1999; TRHEC 2006), while generating other environmental, social, and economic benefits (Krishna 2003; TRHEC 2006). Rainwater harvesting has been defined in numerous ways in literature (Arnold and Adrian 1986; Levario 2007; Gaston 2010). For this study, Rainwater Harvesting Technologies and Strategies (RwHTS) were defined as the *"technologies/strategies used for the permanent collection of rainwater within a given capital project so as to enhance the water* *resources of the area and avoid storm water runoff and complications associated with it, on the ecosystem."* Even though RwHTS has often been addressed as a simple technology/strategy (Burt and Keiru 2009; City of Bellingham 2012), RwHTS can quickly become complex depending upon the end use of conserved water, and the complexity associated with project type, site, and weather (Angrill et al. 2012; City of Bellingham 2012; Chatfield and Coombes 2007; Ibraimo and Munguambe 2007; Jothiprakash and Sathe 2009). Even in states where RwHTS is permitted, the end usage of water is still dependent on the type of building (LIDC 2008). This context specificity complicates the implementation process especially for commercial buildings, and demands the participation of professionals such as designers in the decision process. Thus designers play an important role while designing a building to achieve the level of optimization and utilization from the adoption of technologies and strategies. With designers recommending the implementation of sustainable strategies such as RwHTS from the early phases of a capital project, it is important to understand what factors and attributes result in the adoption of sustainable innovations so that more sustainable innovations can be better promoted in the future.

The concept of innovation was first introduced by Schumpeter in 1934 (Freeman 1989). Since then, the term has evolved in its basic definition, and many new specializations within innovation, such as sustainable innovation, have been developed (Hellstrom 2007; Hines and Marin 2004; Rennings 2000). Innovation has been commonly defined by some authors as "*the use of a non-trivial change and improvement in a process, product, or system that is novel to the institution developing the change"* (Schmookler 1952; Freeman 1997; Slaughter 1998; Slaughter 2000; Blayse and Manley 2004; Sexton and Barrett 2003). Others define innovation as "*any practice or material artifact perceived to be new to the relevant adopting unit"* (Atun and Sheridan 2007; Czepiel 1974; Fichman 1992; Habets et al. 2006; Koebel et al. 2003; McCoy et al. 2012; Rogers 2003). For this study, innovation is defined "*as any practice or material artifact perceived to be new to the relevant adopting unit*." The success of an innovation within a society is gauged by its adoption rate within that society (McCoy 2008). Roger (2003) defines adoption as a decision to make full use of innovation as the best course of action available. Within a society, for any particular innovation, individuals may choose to adopt that innovation or not. The individuals who choose to adopt an innovation are termed as adopters, and individuals who choose to decline adoption (or who have not yet been faced with the decision to adopt) are termed non-adopters (Rogers 2003), for a single point in time on a diffusion curve of an innovation. Adopters are generally characterized as more proactive and non-adopters as more reactive (Rogers 2003). However, adoption of an innovation is not a straightforward process, and attributes of the innovation, contextual factors, and situational factors form an important context for the process of adoption of an innovation (Scott et al. 2008).

Researchers have identified five general attributes of innovations that explain different rates for adoption of an innovation: relative advantage, compatibility, complexity, observability, and trialability (Askarany et al. 2007; Atun and Sheridan 2007; Black et al. 2001; Habets et al. 2006; Koebel 1999; McCoy 2008; Rogers 2003; Scott et al. 2008). Other researchers have also pointed out additional attributes of innovation such as social approval, cost, communicability, divisibility, timing of commitment, profitability, supervision competency, and physical attributes that can be added to the ones initially identified (McCoy 2009; Slaughter 1998; Teng et al. 2002; Tornatzky and Klein 1982). Multiple studies in literature state that except complexity, all of the attributes of innovation are expected to be positively related to adoption (Askarany et al. 2007; Black et al. 2001; Roger 2003). For this study, the initially identified five attributes (complexity, compatibility, observability, trialability, and relative advantage) have been taken into consideration. Of these attributes, observability is the focus of this research. Observability has been defined as the "*degree to which an innovation and its results are visible to others"* (Askarany et al. 2007; Black et al. 2001; Habets et al. 2006; Rogers 2003; Scott et al. 2008). Nieto and Perez-Cano (2004) define observability "*as the extent to which technological knowledge can be observed and detected by people and generally depends on the type of innovation*." Nieto and Perez-Cano (2004) also cite Zander and Kogut (1995) to state that "*observable knowledge is quickly transferred, easily accumulated, and hard to protect within an organization*." Nieto and Perez-Cano (2004) investigated how certain attributes of technological knowledge – "*codifiability, teachability, complexity, observability, and dependency"* – may influence the choices that organizations select for protection of their secrets. According to their study, the probability to adopt an innovation is directly proportional to the ability of the potential adopter to observe an innovation. In contrast, there are studies which have not found observability to be an important attribute for innovation. For example, Habets et al. (2006) discuss attributes of innovation and then analyze alternative transport technologies in the road construction industry with regard to the factors affecting their adoption. Observability was left out of the study as it was considered insignificant. McCoy et al. (2012) analyzed the adoption of Structural Insulated Panels and found compatibility and relative advantage as key attributes for the sustained adoption of innovation after initial adoption. Similarly, Black et al. (2001) examined the case of the consumer adoption of Internet financial services using the attributes of innovation. The innovation attributes were found to be important determinants of consumer's adoption decisions; however, observability did not emerge as the sole important factor in their study, as the use of the Internet for financial services is not visible for other members of the society, and is not widely discussed in a social setting. Literature exists to both support and refute the importance of observability: some researchers have admitted the importance of observability towards encouraging the adoption of innovations, while others have pointed it out to be negligible, depending on the cases being studied. However, at the same time it has also been widely accepted that attributes of innovations do play an important role towards the adoption of an innovation, and all attributes except complexity have been found to have a positive influence on the adoption of innovations. In various studies, the importance of attributes has been found to vary based on the type of innovation that is being evaluated. For example, certain innovations that are visible to the eye will have a higher observability value than others, depending on the unit of analysis.

Generally owners and builders are able to enhance innovation within construction in a number of ways (Blayse and Manley 2004; Koebel 1999) and can sometimes be champions for sustainable innovations. Hendricks and Calkins (2006) found that attributes of the environment were a lower driver for innovation adoption than designers in their study of RwHTS. In addition, as mentioned previously, RwHTS can quickly become complex, especially for commercial projects in developed countries such as the United States due to multiple reasons associated with the project. These facts support the need to study the implementation of RwHTS from the designer's standpoint. Additionally, designers are an integral part of capital projects from their conceptualization to completion, and generally possess the expertise in most stages associated with the design of projects (Ku and Mills 2010; WBDG 2012b), especially commercial projects.

One of innovations increasingly used by designers during the design process has been Building Information Modeling (BIM). The AEC industry is adopting BIM to assist in integrating the often fragmented process for design and construction by eliminating inefficiencies, improving collaboration, and enhancing productivity (Campbell 2007). Various organizations are using BIM to its potential and as per their requirements. This is highlighted by the fact that BIM can be used both as a *product or tool* by the adoption of software and also as a *process* that compliments the adoption of the product/tool. One point that emerges consistently across literature is that BIM carries a wealth of information necessary for many aspects of construction including sustainable design and green certification (Azhar et al. 2008; Mahdavinejad and Refalian 2011; Siddiqui et al. 2009) and at times has been suggested to enhance sustainability (Ku and Mills 2010). On the software side of BIM lies parametric modeling and building simulation that supports either manual or automated data sharing (Morrison et al. 2004; Siddiqui et al. 2009). One of the biggest advantages identified with the use of BIM is visualization, which affords observability of the objects being visualized (Campbell 2007; Staub and Khanzode 2007; Glick and Guggemos 2009) as the components modeled by the potential adopters (Ku and Taibet 2012; Luthra 2010). BIM represents a building with a three-dimensional model with every object having its own identity. Observability is one of the attributes of innovations, and within a BIM domain, it is a key virtue of the whole software integration process where a building is represented as a three-dimensional model, generally with every object having its own identity. With the advantages of interoperability; higher visualization; mostly integrated databases; and unique identity to objects, BIM can enhance observability of innovations, thereby theoretically having the potential to enhance the adoption of sustainable innovations. This thereby can help to improve the sustainability of capital projects and mitigate the negative environmental impacts of the AEC industry. This helps to support the case to investigate whether adoption of BIM results in higher implementation of sustainable innovations such as RwHTS.

4.3 Point of Departure

Studies in literature have shown that the construction industry in the United States has been relatively slow to adopt innovations, and this is also true in regard to sustainable innovations (Dewick and Miozzo 2004; Matar et al. 2008; Mitropoulos and Tatum 1999). Of the various factors that determine the adoption of innovation, attributes of innovation have been found to be key toward enhancing their adoption (Atun and Sheridan 2007; Black et al. 2001; Habets et al. 2006; Rogers 2003; Scott et al. 2008). Habets et al. (2006) cite Tornatzky and Klein (1982) in stating that the perceived attributes of innovation to an adopter are key towards predicting the success of the innovation. It is thought that potential adopters will tend to adopt only those innovations that complement the existing values of the adopting unit. Multiple studies also focus on various attributes of innovation other than observability (Askarany et al. 2007; Black et al. 2001; Habets et al. 2006), and on innovations in multiple other domains. While innovations in other domains have been extensively studied over the last four decades (e.g., Rogers

2003; Tornatzky and Klein 1982), comparatively fewer studies have been conducted which investigate the effects of attributes of innovation upon adoption (Lee et al. 2003) and is further lower for sustainable innovations adopted within design and construction industry. RwHTS is one of the sustainable innovations which has been studied by multiple researchers from the perspective of various stakeholders (He et al. 2007; Hendricks and Calkins 2006; White 2010). Table 4.1 discusses studies identified in the literature with regard to the adoption of RwHTS and the factors/attributes leading to their adoption. As seen from the table, most of the studies are not from the perspective of the designers designing commercial facilities in the United States and does not take into account the two categories of designers (designers who adopt and who do not adopt BIM.)

Table 4.1: Literature review with regard to the adoption of RwHTS

Study	**Unit of Analysis**	**Study intent and findings**
He et al. (2007)	Farmers in China	The study tested 20 variables that effect the adoption of RwHTS using Binary logistic regression. Of those variables 12 were identified to contribute (positively/negatively) towards the adoption of RwHTS. The 12 variables identified were: household head's age, educational background, labor force size, attitude towards RwHTS, contact with extension/NGO, prior training, fertilizer/seed/cash credit, subsidy for RwHTS, participation in Grain-for-Green, type of crop irrigated, walking distance between RwHTS and home, and status of village erosion.
Hendricks and Calkins (2006)	Designers and Owners in the Midwest United States	The study identifies factors, barriers, benefits, and conditions that affect implementation of Green Roofs. The authors found that the design of green roofs was complex, not compatible with existing roofing systems, could not be tried on an incremental basis, with not a great degree of quantified relative advantage. However, green roofs offered some degree of observability not only as a product but also observability in terms of knowledge. Thereby the authors stretched the boundary for observability by not limiting it to just visibility but also to its knowledge aspect. The authors found that stakeholders who were informed about the innovation adopted it more.

Samaddar and Okada (2008)	General Population in Bangladesh and with respect to residential sector	The study analyzed the role of information exchange in the adoption of RwHTS and compared the effectiveness of mass media versus interpersonal sources. The study found that information exchange through interpersonal sources was more effective than mass media. Observation of innovation was not enough for the adoption of innovation in comparison to hearing, but at the same time was effective in spreading ideas farther than hearing. Hearing was effective in close communities whereas observability of innovation crossed boundaries, proving also effective.
White (2007)	General Population in Australia	The study identified the motivation for adoption of RwHTS. Except trialability, all attributes played a role in the adoption.
White (2010)	General Population in Australia	The study evaluated the motivation for adoption of RwHTS. The results show cost and economy, the environment, household independence, and advantages of rainwater harvesting as attributes that lead to adoption of RwHTS. Visibility, which was related with observability, was rated to be of low importance.

Hence, what has not yet been identified is firstly what factors affect the adoption of RwHTS and how observability enhances adoption of RwHTS among the two categories of designers (adopters and non-adopters of BIM). The reason for analyzing adopters and non-adopters of BIM separately is because use of Building Information Modeling (BIM) considerably enhances the observability of an innovation in a virtual world.

With the established importance of adoption of RwHTS, it is important to understand the factors that designers from both adopters of BIM (+RwHTS+BIM) and non-adopters of BIM (+RwHTS-BIM) perceive as influential towards adoption of RwHTS. Also, BIM possesses many capabilities that enhance the design process and provides information to a designer which has not been historically easy to obtain. BIM has been widely promoted as an innovation that not only enhances the data management of projects, but also allows visualization of the systems and products that comprise those projects. Hence it is interesting to see whether enhanced visualization offered by BIM promotes the adoption of RwHTS further how it changes the importance of factors for designers.

This study further sought to determine whether observability played a role in the adoption of RwHTS by a population of designers by developing a mapping of the attributes of innovation to the designer-specified factors associated with the adoption of RwHTS. By exploring the adoption of RwHTS for a sample of southeastern architectural firms, the study explored the question of whether BIM possesses the quality to accelerate the adoption process of sustainable innovations by designers. Among firms that had employed RwHTS on their projects, the study also explored additional factors identified by the adopters of BIM that affected the adoption of RwHTS, but which were not identified by non-adopters of BIM.

Within the larger body of RwHTS, this study focused on five major types of RwHTS: Green Roofs (intensive and extensive), Rainwater storage tanks (above and below ground), and permeable pathways. These RwHTS were selected for following reasons:

- Designers had the most say in the adoption of these technologies compared to other RwHTS
- The initial adoption and design of these five RwHTS did not require any technical specialization beyond the capabilities of a general design firm
- This range of technologies afforded a good blend of observable and non-observable technologies from the standpoint of visibility by the human eye.

For this study, the main population of interest was designers, including adopters of BIM (+RwHTS+BIM) and non-adopters of BIM (+RwHTS-BIM), located along the southeastern coast of the United States. In commercial building projects in the United States, designers typically are an integral part of the project from the conceptualization to completion and are responsible for major design decisions such as the decision to adopt RwHTS. Although owners are able to enhance innovation adoption in construction in a number of ways (Blayse and Manley 2004; Koebel 1999) and can sometimes be champions for sustainable innovations, most RwHTS are technical or complex in nature for commercial projects. Designers are an integral part from the conceptualization to completion of projects, and generally possess the expertise in most stages associated with the design (Ku and Mills 2010; WBDG 2012b). Accordingly, it is worthwhile to study the process of adoption of the RwHTS from the perspective of designers to better understand how to facilitate broader adoption of such technologies on a commercial scale in the future. Thus for this study following research questions were posed:

This section identifies the research questions for this section for this study, as follows:

- Does observability play an important role in the adoption of Rainwater Harvesting Technologies and Strategies (RwHTS)?
- As per literature, BIM enhances visualization and visualization has been linked with observability, so does the use of BIM result in frequent adoption of RwHTS?

4.4 Methodology

This study was built on the results of a survey of RwHTS and BIM implementation by designers along the southeast coast of the U.S. Using the responses from the study, respondents were classified based on whether they had adopted any of the studied RwHTS with or without BIM on projects completed during the period 2000-2010. The firms of interest for this study were respondents that had adopted RwHTS on at least one project. A total of six firms (three +RwHTS+BIM and three +RwHTS-BIM adopter category) were selected for this purpose.

Interviews were conducted with designers to identify factors influencing their decision to adopt RwHTS in projects, and these factors were further investigated with subsequent study. Factors were sorted by designers into categories corresponding to the five attributes of innovations from the literature, and then ranked by importance. The subsequent sections discuss each of these activities in greater detail.

In this research, interviews were conducted with designers representing the six architectural firms selected, generally at a management position, to understand the factors and processes that affect adoption of RwHTS for the two category of participants (+RwHTS+BIM and +RwHTS-BIM). The objectives of this study were to identify factors identified as being relevant to the adoption of RwHTS and map them to the five attributes of innovation based on a sort by participating designers. After identifying and mapping, factors perceived to be important by the participants representing the two categories were also identified. In addition, the researcher also wanted to ascertain whether adoption of BIM contributed to frequent adoption of RwHTS.

After establishing protocols to guide the interviews, a pilot study was conducted with one local firm to test the protocols. For the pilot study, selection of the firm was based on convenience, access, and geographic proximity, which is appropriate for pilot testing as defined by Yin (2009). This selection process based on proximity and previous working relationships allowed for more prolonged and less structured relationship between the researcher and the pilot case respondent. The pilot interview was an informal session that aimed to identify and eliminate possible problems with the interview or with the protocol. Data were collected using the same techniques proposed in the protocol. The recommendations provided by the pilot study respondent helped to enhance the quality of the interview questions and made it more appropriate in regard to the sample. Once the protocols were further refined and tested based on the comments received, the actual case studies could begin.

Upon completion of the pilot study, the interviews for each architectural firm were commenced with two site visits for each participant. Accordingly, a total of 12 site visits were scheduled. Initial contact with the respondent was established via email/telephone, prior to scheduling the site visit. During the initial contact , the respondents were made aware of the aims of the study. As previously mentioned, all selected participants had indicated a willingness to participate in additional study while completing an earlier survey on innovation adoption.

The first site visit aimed to identify factors that affected the adoption of the selected RwHTS by the participants. At the conclusion of the first site visit round for all six firms, a list of factors affecting adoption of RwHTS was compiled and de-duplicated, and factors were compared across firms. The comprehensive, de-duplicated set of factors was transcribed onto individual flashcards where each flashcard listed only one attribute. These flashcards were used as props in the second site visit.

The aim of the second site visit was to let the participants sort the compiled factors that affect the implementation of RwHTS into piles representing the five general attributes of innovations identified in the literature, and then rank these factors in terms of their importance to the adoption process. At the beginning of the second site visit, the participants were provided with a list of the five general attributes of innovation along with their operationalization (Table 4.2).

Table 4.2: Operationalization of the attributes selected from the literature (Based on Rogers 2003)

Attribute of innovation	**Operationalization of the attribute of the innovation**
Complexity	The degree to which an innovation is perceived as difficult to understand and use.
Compatibility	The degree to which an innovation is perceived as being consistent with the existing values, past experiences, and needs of potential adopters.
Observability	The degree to which an innovation and its results are visible to others.
Relative advantage	The degree to which an innovation is perceived as better than the idea it supersedes.
Trialability	The degree to which an innovation may be experimented with, on a limited basis.

Each participant was then provided a pack of flashcards listing the factors identified by all interviewees in the first round of site visits as affecting the implementation of RwHTS. A pile sort constrained methodology (Weller and Romney 1988) was used to allow each participant to classify the flashcard pack of factors into categories representing the five general attributes of innovation. This methodology has been discussed in Chapter 2 of this study. Copies of flashcards were provided in case any of the participants felt that a flashcard was relevant to more than one pile. Also, the participants were asked to think aloud while they conducted the sort so that the thought process could be analyzed. As a result, five piles were created where each pile represented one of the five attributes of innovation. As a general observation, some piles were bigger than their counterparts. This information provided an insight into which of the five attributes from the literature encompassed most of the designer-identified factors.

At the end of the sort, a tabulation of the factors with the sorted attributes was conducted. This was done by the respondent first mentioning each factor associated with the adoption of RwHTS and then the matching attribute to the researcher, and the researcher making a mark on a correlation matrix. Additionally, the sort and tabulation was verified with each participant to validate that the sort was correct according to their perceptions. Thus at the end of this stage, the attributes that impact the adoption of RwHTS according to the participants were matched with the attributes of innovation and the researcher had such six matrices which reflected the sorts of the six respondents.

The next part of the site visit involved ranking the list of factors based on their relative importance toward the adoption of RwHTS, from the most important to the least important. The participants were asked to conduct a sort using a quicksort method (Weller and Romney 1988). This process of quicksort was conducted by asking the participant to select a card from the pile as a standard card. Then all the remaining flashcards were compared to the standard and divided into two piles: the cards “greater than” the standard and those “less than” the standard. This process was repeated for each of the piles formed in the process, until all attributes transcribed on the flashcard were ordered based on the relative importance they had on the adoption of RwHTS. At the end of this stage, results were validated by sharing the ranking with each participant to address possible concerns raised in the literature (e.g., Weller and Romney 1988). By the end of this process, the factors impacting the adoption of selected RwHTS were ranked as per the experience of each of the respondents and there were six ordered lists which reflected the ranking of the six respondents. The completion of these tasks marked the end of the data collection for the six separate cases.

Now, analysis of the data collected was done on a case-by-case basis. As discussed earlier, there were two major categories of firms being considered in this study: (+RwHTS+BIM) and (+RwHTS-BIM). The data obtained from pile sorts from the two categories was analyzed separately in order to evaluate the influence of BIM on adoption of RwHTS.

For the pile sort, each respondent had one opportunity, unless they requested otherwise, to map the factor against the attribute by sorting the card into the associated attribute’s pile. In this case each mapping was considered as a single vote to select an attribute. In such a selection process, a plurality method emerged as the best fit to conduct the analysis of the data. Hence, the plurality approach was used to obtain a consensus among the pile sort for each of the two categories. The plurality method is used as a means of ranking options where a candidate with the most first place votes wins (PBS 2013). In this case, instead of candidate, an attribute was ranked. For each factor there were three votes casted by the three respondents from each category, mapping it with the attribute of innovation. Based on the vote count, whichever attribute received the maximum votes had that particular factor associated with it. In case of a tie, both tying attributes were associated with the factor. The outcome of this process was that factors associated with the adoption of RwHTS were mapped with the innovation attributes separately for the two groups [(+RwHTS+BIM) and (+RwHTS-BIM)].

After completing the pile sort, the data derived from quick sort was analyzed. In this case again the two categories were analyzed separately. Rankings conducted by each respondent within each category were analyzed in terms of mean, median, and the spread between the data points to identify the factors which were perceived to be important for the adoption of the RwHTS by the two categories of the respondents. By the end of this process factors associated with the adoption of RwHTS were identified for the two groups namely (+RwHTS+BIM) and (+RwHTS-BIM), as per the importance provided by the respondents.

4.5 Results

After interviewing the participants from the six firms, factors affecting the adoption of RwHTS were identified, compiled, and de-duplicated. Table 4.3 discusses the factors identified by the respondents from both of the categories.

Table 4.3: Factors identified by the participants that affect the adoption of RwHTS

Aesthetics
Code
Cost
Design expertise
Education of the community surrounding the project
Education of the occupants
Internal building demands
Knowledge of technology
LEED certification
Overall environmental choice
Owner orientation/Receptiveness
Owner requirement
Project size
Project context specific
Project environmental goals
Project irrigation requirements

Realization of limited resources by general population
Robustness of the system
Site climatic conditions
Site environmental condition
Site location
Site size
Stewardship of site
System complexity
Type of plantation on site
Water quality output from site

In all, 26 factors were identified by respondents that affected the adoption of RwHTS in commercial projects. Additionally, when asked, respondents from both of the categories stated that in their opinion BIM, as of now, did not offer any specific advantage that could enhance the adoption of the RwHTS. There were multiple reasons cited by the participants of the two categories for the response, including:

- Most of the required calculations for RwHTS are straightforward enough that they could be implemented in a spreadsheet, which was more familiar in general than BIM (Mentioned by +RwHTS-BIM).
- There was perceived to be no need for additional complicating information to support decision making (Mentioned by +RwHTS-BIM).
- Within BIM, there was a lack of specific software that could be used for the implementation of RwHTS and could incorporate complex calculations, compared to what is incorporated currently (Mentioned by +RwHTS+BIM).

As mentioned by the participants, there was an indication that adoption of BIM did not offer any specialized advantage to the potential adopters, given the way BIM was used by participants. However, during the initial analysis of the data obtained from two sets, the following five factors were identified by adopters of BIM (+RwHTS+BIM) but *not* by non-adopters of BIM (+RwHTS-BIM) as being relevant in their decision to adopt RwHTS on a project:

1. Aesthetics
2. Education of the occupants
3. Internal building demands
4. Project context specific
5. Project environmental goals

The addition of these five factors by the adopters of BIM (+RwHTS+BIM) did not conclusively prove that BIM offered any new functional aspects to the potential adopters. This was specifically identified in the previous section when respondents were queried about the role of BIM in RwHTS adoption. However, at the same time, none of these factors were identified by any respondents from the other category, non-adopters of BIM. One possible explanation could be fatigue encountered by the respondents over the course of the interview. Another possible explanation may be that participants did not feel that these factors are important towards the adoption of innovation. Hence with these explanations the researcher continued the analysis further. The next section discusses the mapping of the identified factors upon the attributes of innovation by the respondents of (+RwHTS+BIM) and (+RwHTS-BIM).

4.5.1 Mapping of factors

After identifying, compiling, and de-duplicating all 26 factors, all factors were mapped with respect to the five attributes of innovation by respondents from both categories (+RwHTS+BIM) and (+RwHTS-BIM). The ranking and mapping by the two categories was kept separate as they represented two different genres of designers. The mapping was developed by conducting a pile sort and the responses for each mapping were selected on the basis of the plurality method. So, for example if one participant mapped "C*ode"* to "*Compatibility"*, but two participants mapped it to "*Complexity"*, during the final analysis, complexity was selected since it received more votes. This way the final mapping was incorporated for all 26 factors within both the categories.

For the respondents representing (+RwHTS–BIM), as seen in Table 4.4, seven factors could not be mapped only to one particular attribute, since respondents uniformly distributed their votes for mapping and no convergence could be achieved. In this case, one factor was applied to multiple attributes.

Table 4.4: Mapping of factors to more than one attribute by (+RwHTS–BIM)

	Compatibility	**Complexity**	**Observability**	**Relative advantage**	**Trialability**
Code		√		√	
Design expertise	√	√			√
Education of the occupants		√	√		√
Owner orientation/ receptiveness	√	√		√	
Project environmental goals	√			√	√
Realization of limited resources by general population	√		√	√	
Water quality output from site	√	√			√

No obvious explanation emerged for the uniform mapping of factors onto the attributes of innovation. Future investigations may be able to address this issue by increasing the number of respondents, although this would not guarantee any change in mapping by respondents.

Additionally, during the process of mapping, the following attributes were discarded or mapped twice by the respondents from the category of (+RwHTS-BIM):

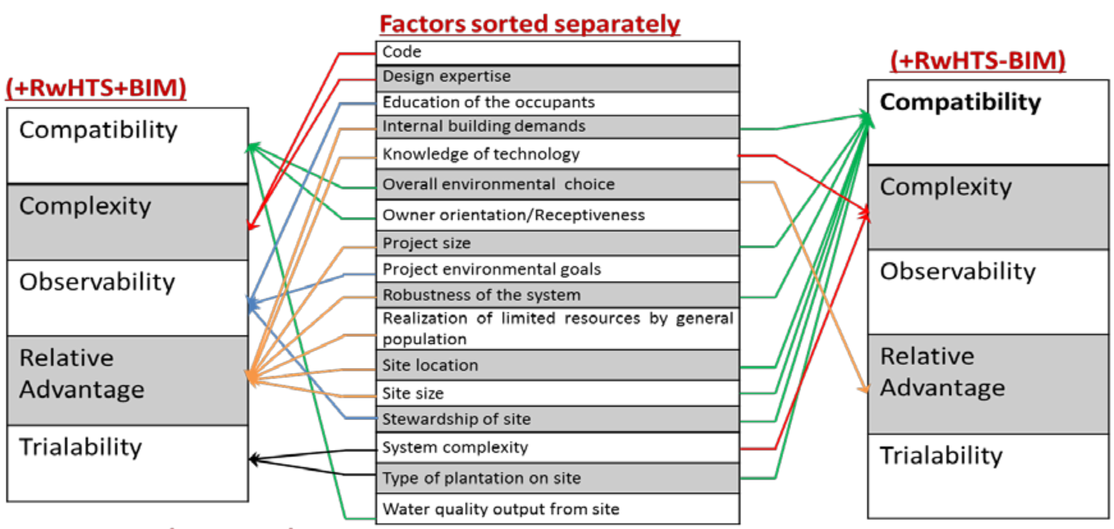
- "*Code*" could not be mapped onto any of the attributes of innovation, by one of the respondents, as the respondent felt that none of the five attributes of innovation could compliment or support code, as it was a prerequisite for the implementation of RwHTS. Without the code allowing the implementation of RwHTS, it was not possible to implement. In this case it was counted as an invalid vote for that particular factor and only two votes were counted. The two remaining votes mapped "*code*" to two different categories. Hence, a consensus could not be achieved as the remaining two mapped "*code*" onto complexity and relative advantage.

- “*Stewardship of site*” was mapped twice on compatibility and observability by one of the respondents. In that case, the single vote was split into 0.5 each for each factor, since every respondent had only one vote.

No such occurrence was observed for the mapping conducted by the respondents representing the adopters of (+RwHTS+BIM) category.

Figure 4.1 depicts the mapping of factors over attributes by the participants representing the two categories: (+RwHTS+BIM) and (+RwHTS-BIM). During the process of mapping, the following observations were made in regard to the commonalities observed between the mapping conducted by the respondents representing the categories of (+RwHTS+BIM) and (+RwHTS-BIM):

- Nine different factors were mapped with compatibility, observability, and relative advantage.
- Of the nine factors, five factors were associated with compatibility by the respondents of both categories.
- Complexity and trialability did not encompass any factor.



Factors sorted commonly

Compatibility	Complexity	Observability	Relative Advantage	Trialability
• Owner requirement • Project context specific • Project irrigation req. • Site climatic conditions • Site environmental condition		• Aesthetics • Education of the community surrounding the project • LEED certification	• Cost	

Figure 4.1: Mapping of factors over attributes by the participants from (+RwHTS+BIM) and (+RwHTS-BIM)

Based on the analysis of the mapping conducted by the respondents of the two categories, the following conclusions can be derived:

- One common similarity that could be observed from the sort conducted by the respondents of the two categories was that "compatibility" covered the maximum number of discrete designer-identified factors that lead towards adoption.
- Factors identified to be associated with observability, relative advantage, and trialability increase when the mapping is conducted by (+RwHTS+BIM). The reason for such an observation can be attributed to the notion that BIM provides a platform to the designers where they can try the RwHTS, visualize the system and its benefit, therefore study observes more factors associated with observability, relative advantage, and trialability.
- BIM allows users to try systems without actually implementing in the physical world, thereby enhancing visualization, advantages of the system, and reducing complexity for the potential adopter. For this reason the study observed "*system complexity and type of plantation*" associated with trialability by the adopters of BIM. For non-adopters of BIM the two factors were mapped with complexity and compatibility respectively. And for the previously mentioned reason, the study also observed that users of BIM mapped more factors with observability, relative advantage, and trialability.
- Observability does not encompass most factors for any of the mappings. For the category of (+RwHTS+BIM), compatibility and relative advantage equally encompass most factors. And for the category of (+RwHTS-BIM), compatibility encompasses maximum factors.
- A noticeable difference between the mappings can be seen for the two categories.

The next section discusses the ranking of the factors associated with the adoption of RwHTS by the two categories of respondents (+RwHTS+BIM) and (RwHTS-BIM)

4.5.2 Ranking of factors

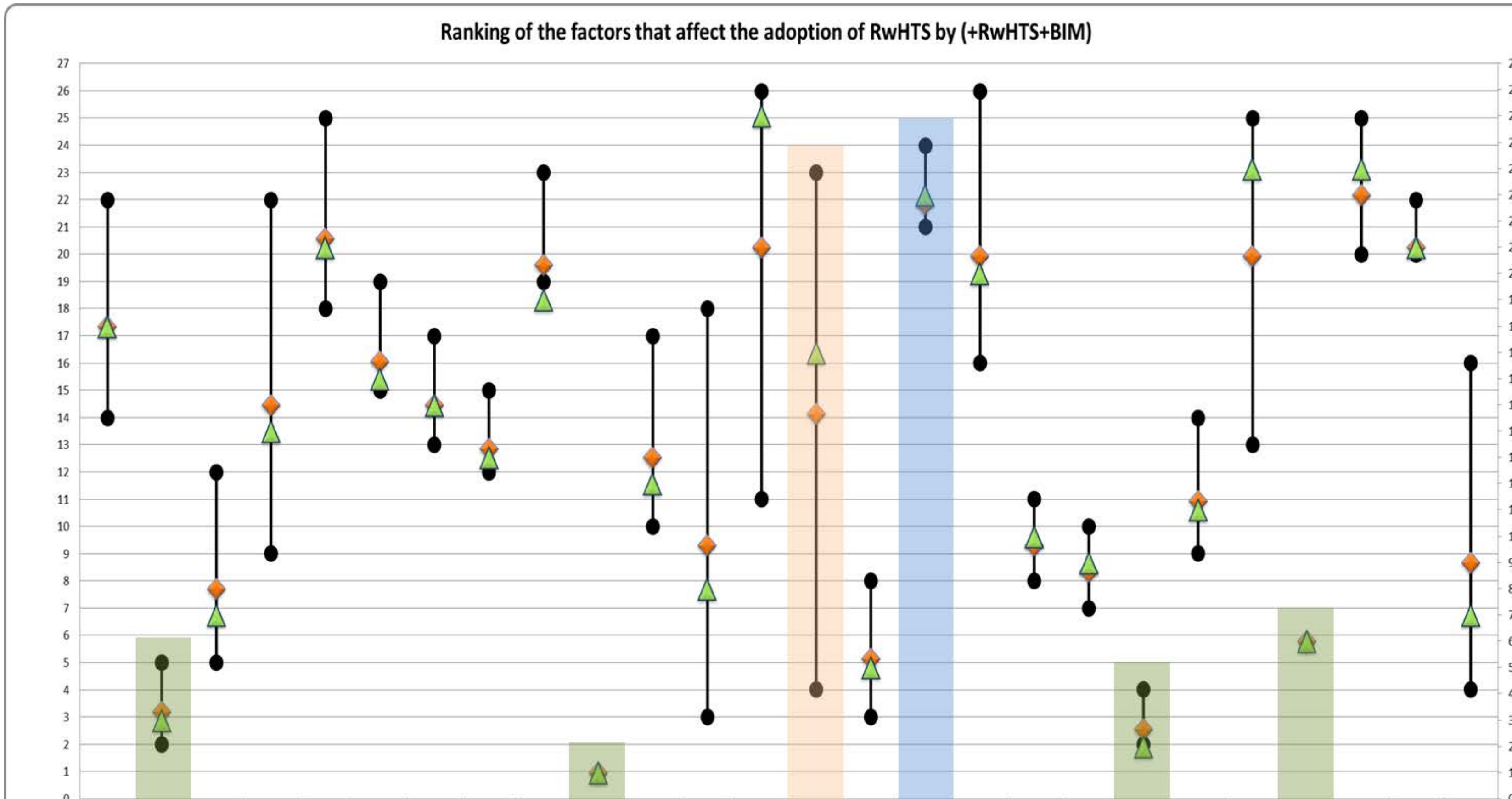
The main aim of this section was to identify the factors which are perceived to be important for the adoption of RwHTS by the respondents of (+RwHTS+BIM) and (+RwHTS-BIM). This was conducted by ranking factors by the two categories of respondents. The results from the two categories were kept separate as they represented two different genres of designers. Rankings developed for each category was analyzed by combining the results of the whole category and observing mean, median, and the spread of the outcome. During the process of ranking, the "*design expertise and knowledge of* *technology*" was discarded by one particular respondent from the category of (+RwHTS-BIM). The reason provided was that no RwHTS could be implemented properly without design expertise and the knowledge of the system, and so were prerequisites for the adoption of the RwHTS. However, other respondents from this category did not discard the factor. Figure 4.2 and 4.3 represent how factors were ranked overall by the respondents of the each category. The proceeding section discusses the ranking for each of the categories in detail

4.4.2a Ranking for (+RwHTS+BIM)

Based on the analysis of Figure 4.2, code, site environmental conditions, overall environmental choice, and stewardship of the site emerged as the factors which played an important role in the adoption of the RwHTS. The emergence of code as an important factor for adoption of the RwHTS can be attributed to the fact that regulations need to approve the implementation of RwHTS on site prior to adoption. Therefore, regulations play an important role in the adoption of the RwHTS. Environmental conditions are also important as they have to compliment with the type of RwHTS that a designer hopes to implement. "Project irrigation requirements" emerged as the factor which was given least importance among the 26 factors. In addition, the maximum spread among the responses of the respondents was observed for the factor "project context specific". One reason that could be attributed to such a wide spread could be that the factor was interpreted in multiple ways by the respondents, but at the same time, there was no proof that such was the case. Furthermore, as observed in the previous chapter that BIM enhances observability, but the adopters of BIM did not feel that aesthetics was an important factor. This reduced realization to be attributed to the fact that the respondents already possess the tools to decide on the aesthetics and so did not give a higher importance to it.

4.5.2b Ranking for (+RwHTS-BIM)

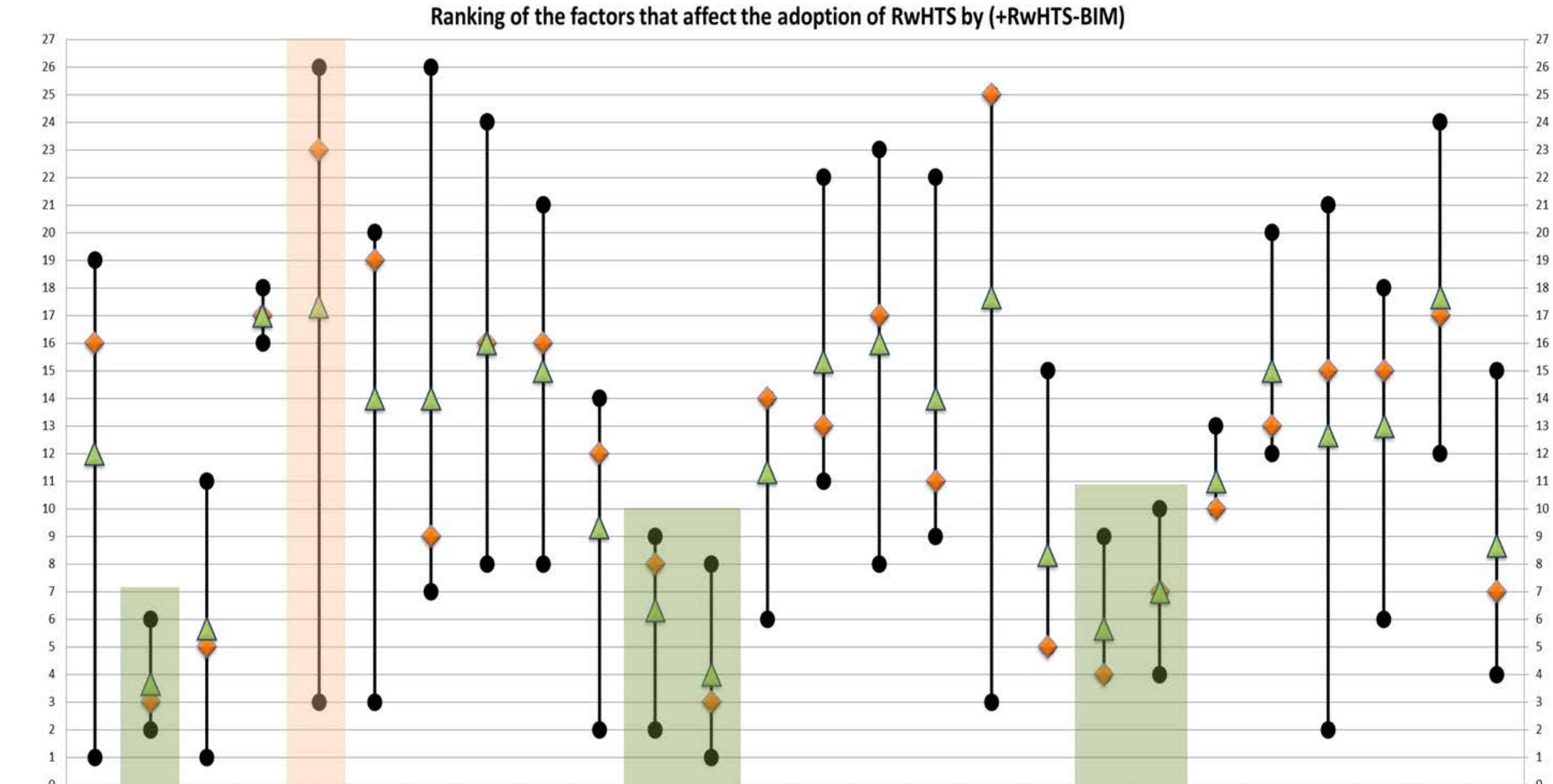
Based on the analysis of figure 4.3, code, site environmental conditions, site climatic conditions, owner requirement, owner orientation, and site climatic conditions emerged as the factors which played an important role in the adoption of the RwHTS. The identification of first two factors (code and site environmental conditions) as important by the respondents of this category is similar to the ranking observed for the previous category. "Code and site environmental conditions" were perceived as important by the respondents of the two categories due to reasons mentioned in the previous section.



	Aesthetics	Code	Cost	Design expertise	Edu. of the community surrounding the project	Edu. of the occupant	Internal bldg. demand	Knowledge of tech.	LEED cert.	Overall env. choice	Owner orientation	Owner req.	Project size
Comp. 1	22	2	5	9	18	15	13	12	19	1	17	3	26
Comp. 2	14	5	12	22	25	19	17	15	23	1	10	18	11
Comp. 3	18	3	7	14	21	16	15	13	19	1	12	8	26
◆Average	18.0	3.3	8.0	15.0	21.3	16.7	15.0	13.3	20.3	1.0	13.0	9.7	21.0
ΔMedian	18.0	3.0	7.0	14.0	21.0	16.0	15.0	13.0	19.0	1.0	12.0	8.0	26.0

	Project context specific	Project env. goals	Project irrigation reqs.	Realization of ltd. resources by gen. population	Robustness of the system	Site climatic cond.	Site env. cond.	Site location	Site size	Stewardship of site	System complexity	Type of plantation on site	Water quality output from site
Comp. 1	23	8	24	16	11	10	4	14	25	6	20	21	7
Comp. 2	4	3	21	26	8	7	2	9	13	6	24	20	16
Comp. 3	17	5	23	20	10	9	2	11	24	6	25	22	4
◆Average	14.7	5.3	22.7	20.7	9.7	8.7	2.7	11.3	20.7	6.0	23.0	21.0	9.0
ΔMedian	17.0	5.0	23.0	20.0	10.0	9.0	2.0	11.0	24.0	6.0	24.0	21.0	7.0

Figure 4.2: Ranking of factors that affect the adoption of RwHTS by (+RwHTS+BIM)



	Aesthetics	Code	Cost	Design expertise	Edu. of the community surrounding the project	Edu. of the occupant	Internal buildg. demand	Knowledge of tech.	LEED cert.	Overall env. choice	Owner orientation	Owner req.	Project size
Comp. 1	1	6	5		3	3	9		16	2	8	8	14
Comp. 2	16	2	1	18	26	19	7	24	8	12	9	3	14
Comp. 3	19	3	11	16	23	20	26	8	21	14	2	1	6
◆Average	16.0	3.0	5.0	17.0	23.0	19.0	9.0	16.0	16.0	12.0	8.0	3.0	14.0
△Median	12.0	3.7	5.7	17.0	17.3	14.0	14.0	16.0	15.0	9.3	6.3	4.0	11.3

	Project context specific	Project env. goals	Project irrigation req.	Realization of ltd. resources by gen. population	Robustness of system	Site climatic cond.	Site env. cond.	Site location	Site size	Stewardship of site	System complexity	Type of plantation on site	Water quality output from site
Comp. 1	11	8	9	3	15	4	4	10	13	2	15	12	7
Comp. 2	22	23	11	25	5	4	10	13	20	21	6	17	15
Comp. 3	13	17	22	25	5	9	7	10	12	15	18	24	4
◆Average	13.0	17.0	11.0	25.0	5.0	4.0	7.0	10.0	13.0	15.0	15.0	17.0	7.0
△Median	15.3	16.0	14.0	17.7	8.3	5.7	7.0	11.0	15.0	12.7	13.0	17.7	8.7

Figure 4.3: Ranking of factors that affect the adoption of RwHTS by (+RwHTS-BIM)

It was also observed that the factor, “education of the community surrounding the project,” was perceived as least important by the respondents of this category. This factor also encompassed the maximum spread among the responses of the respondents. The reason for such a wide spread of the response could not be attributed to one particular reason. However, on a general basis it could be assumed that some designers within this category gave high priority to the education of the stakeholders surrounding the project and some did not, thereby resulting in a high spread. The least important factor for this category, “education of the community surrounding the project,” was different from the previous category (Project irrigation requirements). But then the difference was very close, and it cannot be rejected that “project irrigation requirements” is given a nominal importance. In addition, it was also observed that LEED was not considered as an important factor by any of the two categories. This can be attributed to the fact that LEED has allocated insignificant points towards this issue, which has also been reflected in the report by McGraw-Hill (2010). In addition, for both the categories, cost was given a medium level importance.

4.6 Limitations and future research

A major limitation of this study was the number of respondents. Only three respondents from each category proved to be somewhat limiting, especially in the category for (+RwHTS-BIM). This emerged during the study due to lack of consensus during the mapping process for this category of participants. It is expected that a sort could have been normalized by increasing the number of respondents, although this may not necessarily be the case. A higher number of participants could also have enhanced the generalizability for the study and resolved the issue with convergence in regard to sorting of each group. However, the detailed case study approach used in the overall study meant that it was necessary to focus on a small number of cases and triangulate across only three cases in this exploratory phase of the work. This study is the first step toward answering the questions posed in this research, and further studies can be carried out to determine if by increase in size a higher convergence can be achieved, or are the factors equally associated with multiple attributes, as seen in this study.

The study indicated that other attributes of innovation for both categories of adopters are associated with factors which are perceived to be more important than observability. Based on the data derived from the sorts, it can be concluded that observability does not play as important a role in comparison to other attributes for the adoption of the selected RwHTS as other attributes do. An important expansion of this study would be to replicate the study on a different stakeholders of the industry and observe the difference. As per Lee et al. (2003), we need to conduct more studies that analyze the importance of attributes of innovations with regard to general sustainable innovations. This identification would help product manufacturers and suppliers better orient their products to promote more widespread and effective adoption.

4.7 Contributions

This section identifies contributions made to the existing body of literature, as follows:

- The study established a rank order of the factors associated with the adoption of RwHTS. Overall, environmental choice and codes emerged as the top factors that impact the adoption of RwHTS from the perspective of adopters of RwHTS+BIM and adopters of RwHTS-BIM respectively.
- Rankings supported the conclusion that observability was less important than other factors in adoption decisions, which is congruent with previous studies conducted in the literature. Compatibility was relatively more important in the adoption of RwHTS for both BIM adopters and non-adopters.

4.8 Impacts

- Interpersonal channels and attributes of innovation have been some of the factors identified in the literature that affect the adoption of innovation and RwHTS (Samaddar and Okada 2008). When Interpersonal channels are used, an exclusive list of factors can further help the adoption of RwHTS. Thus identification of factors that contributed towards the adoption of RwHTS can be provided to the potential adopters to aid with the process of adoption. This can be also used by designers/owners/facility managers and other important stakeholders associated with the buildings who are adopting the identified RwHTS for the first time.

Chapter 5: Observing commonalities in design process and the influence of BIM adoption on the design process for green buildings

5.1 Abstract

Green buildings are different from conventional buildings, as they are designed, built, renovated, and/or operated in an ecologically and resource-efficient manner and utilize processes or products that help accomplish long-term cost savings over the life cycle. The design process for conventional buildings is largely fragmented and disjointed, in comparison to the design process of green buildings. At the same time, however, the design process can become easily complex due to numerous factors such as adoption of new systems/strategies/technologies, increased cross-functional stakeholders, increased expectations by the stakeholders, and other factors. To manage the complexity of this process, visualization tools facilitate better communication and collaboration resulting in better integration of the design process. Building Information Modeling (BIM) is one such concept which can be used by designers and other key stakeholders. This descriptive study aimed to understand the design process followed by the designers of green buildings employing Rainwater Harvesting Technologies and Strategies (RwHTS). Specifically, this study explored whether the adoption of BIM changes the way green buildings are designed and whether adoption of BIM is associated with more frequent adoption of RwHTS. For this study, six firms were purposively selected based on responses to a regional survey on adoption of RwHTS and BIM. A holistic multiple case study method was used to identify the design process followed for green buildings where RwHTS were implemented. Interviews were used as a part of the holistic multiple case study to observe whether the implementation of BIM influenced the adoption of RwHTS. Data were generated in form of process maps and text to answer the research question. Based on the comparative analysis of responses from the respondents, the study characterized the design process followed by designers to design a green building and generated a common process that was representative of the processes across the set of participants. The differences in process to design a green building by adopters of (+RwHTS+BIM) versus adopter of (+RwHTS-BIM) were also identified.

5.2 Introduction and Background

Historically, the planet has been perceived as a virtually limitless source of materials and energy, and as an unlimited repository for waste (Kibert et al. 2002; McCoy et al. 2012). This perception has led to buildings that are extremely resource intensive (Kibert et al. 2002). However, the sustainability of the design and construction industry and the ongoing availability of natural resources for construction are dependent on a fundamental shift in resource utilization (Kibert et al. 2002). Resource utilization has become critical as 10% of the global economy is based on constructing, operating, and equipping buildings for operations (Chen and Chambers 2010; Roodman and Lenssen 1994), and the fact that these resources are finite (WWF 2012). Improved utilization of resources in regard to buildings can be achieved in numerous ways, including the way buildings are designed and operated and the materials selected for construction. In this process a paradigm shift can be achieved where resource consumption is more cyclic in nature.

In order to achieve resource optimization, designers, along with owners, play an important role while designing a building. Every design decision made for a building, including adoption of new products or processes, has an impact on future availability of limited environmental, social, and economic resources. In order to develop new ideals of sustainability, the Architecture, Engineering, and Construction (AEC) industry needs to adopt innovations that are more sustainable than their current counterparts, thereby resulting in buildings that are greener or more ecologically responsive, are acceptable within the existing norms of society, improve the quality of life for their occupants either incrementally or radically, and pave the way for buildings that are sustainable over a continuum of time.

A "*green*" building is generally different from a conventional building as they are designed, built, renovated, or operated in an ecologically and resource-efficient manner (USDOE 2003; Horman et al. 2006; Dick 2007) and often utilizes processes or products that help accomplish economical savings apart from conserving the environment and improving the health of the occupants (EPA 2012). Apart from conserving natural resources, green buildings also possess the potential of enhancing indoor environmental quality, which in most cases improves the occupant health and productivity (Environmental Building News 1999; EPA 2012; Magent et al. 2005; Horman et al. 2006). The United States Environmental Protection Agency (USEPA 2010) defines green building as "*the practice of creating buildings and utilizing environmentally and resource efficient products/processes throughout building's life-cycle*." For this study, green buildings have been operationalized as *"facilities that qualify to utilize and reduce the consumption of natural resources in an efficient manner."* In the context of this study, buildings do not need to be certified by an existing rating tools such as Leadership in Energy and Environmental Design (LEED), the Nation Association of Home Builders (NAHB) green standard, or Green Globes in order to be considered green.

The design process for green buildings is intensive and iterative between owner, designers, and other stakeholders, since it serves as the method for realizing the goals outlined for the project (Hackler and Holderen 2008). In general, such projects begin with identification of Owner Project Requirements (OPR) (Magent 2005). Compared to conventional projects, green buildings are often referred to as "*front end loaded, human energy intensive exercise(s)*" (Kobet et al. 1999) which encompass interdisciplinary collaboration from the conceptual design phase in order to achieve successful integration of building systems (Horman et al. 2006; Reed and Gordon 2000). Green projects do all this while accomplishing the goals and aspirations of their stakeholders, within established ecological and economic parameters. Additionally, due to the highly collaborative nature of the delivery process for green buildings, the number and intensity of interactions are increased between stakeholders, and thus interpersonal skills become more critical. (BHKR 2003; Magnet 2005).

In contrast, the design process for conventional buildings, or the traditional process, is largely fragmented and disjointed. Often described with discrete milestones such as "*schematic design*" and "*design development*" (Horman et al. 2006; Magent et al. 2005), the traditional design process is compartmentalized and linear, with upstream design decisions severely impacting downstream building performance. Researchers have also pointed out that the traditional design process encourages isolation of stakeholders during the design and construction phase (Kashyap et al. 2003) and the interaction of information amongst various stakeholders is sparse. Additionally, this isolation coupled with fragmented design and construction data can lead to exorbitant changes during construction, duplication of efforts, and redundancies in the final design, which at times can result in buildings that either operate below optimum potential (Magnet 2005) or even sometimes fail to meet the OPR/expectations. Magent (2005) cites The American Council of Engineering Companies to highlight the importance of design process with respect to the quality of design document and state that there are multiple factors which affect the quality of the design document including the fragmentation of stakeholders over the design and construction of the facility. With these point there are indications that design process is important not only for the quality of deign documents but also for accurate realization of the OPR. The process of design becomes more critical if the building designed is green as such buildings are more complex, has more stakeholders involved, and demands higher collaboration, in order to successfully realize the OPR. Thus there is a greater likelihood that the design process for a green building is likely to be different than the design process for conventional buildings.

In parallel with the emergence of green buildings as a trend, Building Information Modeling (BIM) has emerged in the industry as an innovation to support the process for design and construction not only at the beginning but through the life cycle of the building. Green buildings necessitate a degree of interdisciplinary collaboration as they require complex analysis and careful material and system selection, particularly from the very early process for design (Riley et al. 2004), especially if stakeholders intend to maximize benefits from the adoption of sustainable strategies (WBDG 2012c). To reduce the complexity of this process, tools which enhance visualization, such as BIM can reduce confusion facilitate better communication, and collaboration between stakeholders, hence providing an overall better integration of the design process (Korkmaz et al. 2010). BIM can be used by project stakeholders, including designers, not only as a process but also as a product/tool (Eastman et al. 2008; Jerignan 2007; Ku and Taibet 2011; Succar 2009). BIM possesses the capability of enhancing visualization and collaboration, eliminating or reducing inefficiencies and redundancies, improving collaboration, and enhancing productivity (Campbell 2007; Staub and Khanzode 2007; Glick and Guggemos 2009). It is also a representation of all characteristics (functional and physical) of a designed building (Sebastian et al. 2009) that stores all the information relevant to the project (Bratton 2009). Multiple uses and benefits of BIM are possible and dependent on the users and the level at which they are willing to adopt the concept. Analysis of multiple studies yields similarities between green buildings and BIM, including:

- Need for adopting interdisciplinary approach and active stakeholder participation from the very beginning of the project (Arayici et al. 2012; Horman et al. 2006; Jerengen 2007; Nies and Krygel 2008).
- Need for a champion to support successful adoption, who at the same time will be technologically competent to resolve any issues that may arise (AGC 2007; Jerengen 2007; Mesnar 2011).
- Tendency for partial adoption that results in reduced benefits to the adopting units.

With all the benefits of BIM and its potential to alter the way the AEC industry has operated, there are still certain drawbacks that BIM possesses (Korkmaz et al. 2010). For example:

- Currently certain BIM tools are labor intensive and costly due to the time associated with the creation of the models (Zhilang and Li 2008).
- The issues related to the ownership of the model can limit/reduce the perceived benefits, if not resolved in the beginning (AGC 2007).
- The issues related to the accuracy of the model raise concern, if protocols are not established for the whole team at the beginning (AGC 2007).

- At present certain software products used by professionals in disciplines associated with design are not interoperable and the flow of information between then is not parametric in nature (Zhilang and Li 2008).

Given these shortcomings, BIM's success in capital projects requires that the applications of BIM tools should align with the priorities of the projects, focus on the problematic areas that need interdisciplinary decision making, and enable better systems understanding for integrated teams. However, BIM still has the potential to complement the design process for green buildings, and assist stakeholders in their decision to employ green innovations. One of the multiple ways to establish the adoption of BIM on green projects successfully is by outlining the priorities/expectations for BIM, establishing protocols for data sharing and management, identifying the level at which BIM will be used, and outlining the roles, responsibilities, and expectations for each stakeholder in regard to the adoption of BIM from the very beginning of the project (AGC 2007; Mesnar 2011) and then integrating these with the overall OPR.

Thus design and implementation of green buildings offer a way to reduce the human impact on ecosystems and resource bases. In addition, design of green buildings has been perceived to be more interactive, collaborative, and intensive than the traditional process. The design of green buildings is further complicated by factors such as increased number of stakeholders, increased amount of information exchange, higher expectations, and others. BIM has been seen as one of multiple solutions available at this time to reduce and manage the complexity associated with the design of green facilities. In addition, similarities between design of green building and implementation of BIM on projects has been observed. But even with these benefits, certain shortcomings are also a risk and offer opportunities for improvement. The next section discusses the point of departure for this research and further paves the way for the research questions established for this study.

5.3 Point of Departure

The process mentioned in the prior section for designing a green building needs to be able to incorporate checks and balances, identify and determine the rationale prior to adoption of sustainable innovations, and afford holistic and systematic analysis of innovations to be adopted. This "*systematic, rational, and holistic process*" for design followed by designers often concurs with the definition established for the so-called "*first generation design method*" (Archer 1965; Cross 2006). First generation design method is mainly found in engineering and industrial design and the second generation design method is mainly found within the realms of architecture and planning (Cross 2006). However, with the advent of green buildings, there is indication that green building design lies more within the category of first generation design methods than any other, although this has yet to be systematically studied. This is due to the variable and complex nature of the design which is highly depending on the type of project (Magent 2005). Additionally, Korkmaz et al. (2010) point out that the current lack of design process guidance can lead to sub-optimal decisions which result in repeated mistakes. Although numerous guidebooks/models have been published which focus on the technical aspects of sustainable design or engineering design (e.g., Harvard University Office for Sustainability 2009; City of Chicago; USGBC 2009), little has been published to discuss the design process in itself (Mendler and Odell 2000). Vanegas (2003) presents information about the design process that needs to be followed by the industry for the design of green buildings. In addition there are recommendations of the American National Standard Institute (ANSI) for integrated design. However, what needs to be tested is whether the industry is actually following such principles and observe the real patterns followed by architectural firms which are prone to external variables and constraints such as varying codes, budget, project requirements, stakeholder expertise, varying expectations of stakeholders, and other factors.

In this investigation, Rainwater Harvesting Technology and Strategy (RwHTS) will be used as an example of green technology to achieve consistency across cases, not because of any particular significance in and of itself, but because it is likely to be typical of other types of designed systems. Thus this study aimed to address the following research objectives:

- Identify the design process followed by architectural firms for private sector owners who intend to build a green building that incorporates Rainwater Harvesting Technologies and Strategies (RwHTS) installed within.
- Identify any commonalities in the design process across firms.
- Evaluate whether adoption of BIM changes the way green buildings are designed.
- Investigate whether designers used BIM to enhance the acceptance of RwHTS during design.
- The next section discusses the methodology followed for this study.

5.4 Methodology

This study was built on the results derived from an investigation of RwHTS and BIM implementation by designers in the southeast coast of the U.S. Using the responses from this precursor study, a total of six firms (three +RwHTS+BIM and three +RwHTS-BIM) were selected for this study. As a backup, an equal number of organizations were identified and held as reserve in case the initially selected firms decided not to participate. Case studies were conducted with designers representing the six architectural firms selected, generally at a management position, to understand the design process followed within each of the architectural firms. The objectives of this study were to identify the design process followed by the architectural firms for private sector owners who intend to build a green building which incorporates Rainwater Harvesting Technologies and Strategies (RwHTS) installed within. In this process the aim was to ascertain whether adoption of BIM changes the way green buildings are designed. The following section discusses the specific tasks incorporated for this study.

5.4.1 Design and conduct study

The methodology shown in Figure 5.1 depicts the research process followed for this study. This methodology has been developed on the basis of the case study model, cited from Yin (2009). The second stage aimed at developing case studies of three shortlisted firms for each of two types of design firms: adopters of (+RwHTS+BIM) and (+RwHTS-BIM). An approach using multiple case studies with a holistic design was used to resolve the research question in this phase mainly because of the following factors:

- The study aimed at understanding the design process adopted by the firms, which in turn helped understand the nature of the organization and required a holistic model
- Studies in literature suggest that evidence from multiple case studies are more compelling and the resultant study is often regarded as being more robust (Herriott and Firestone 1983).

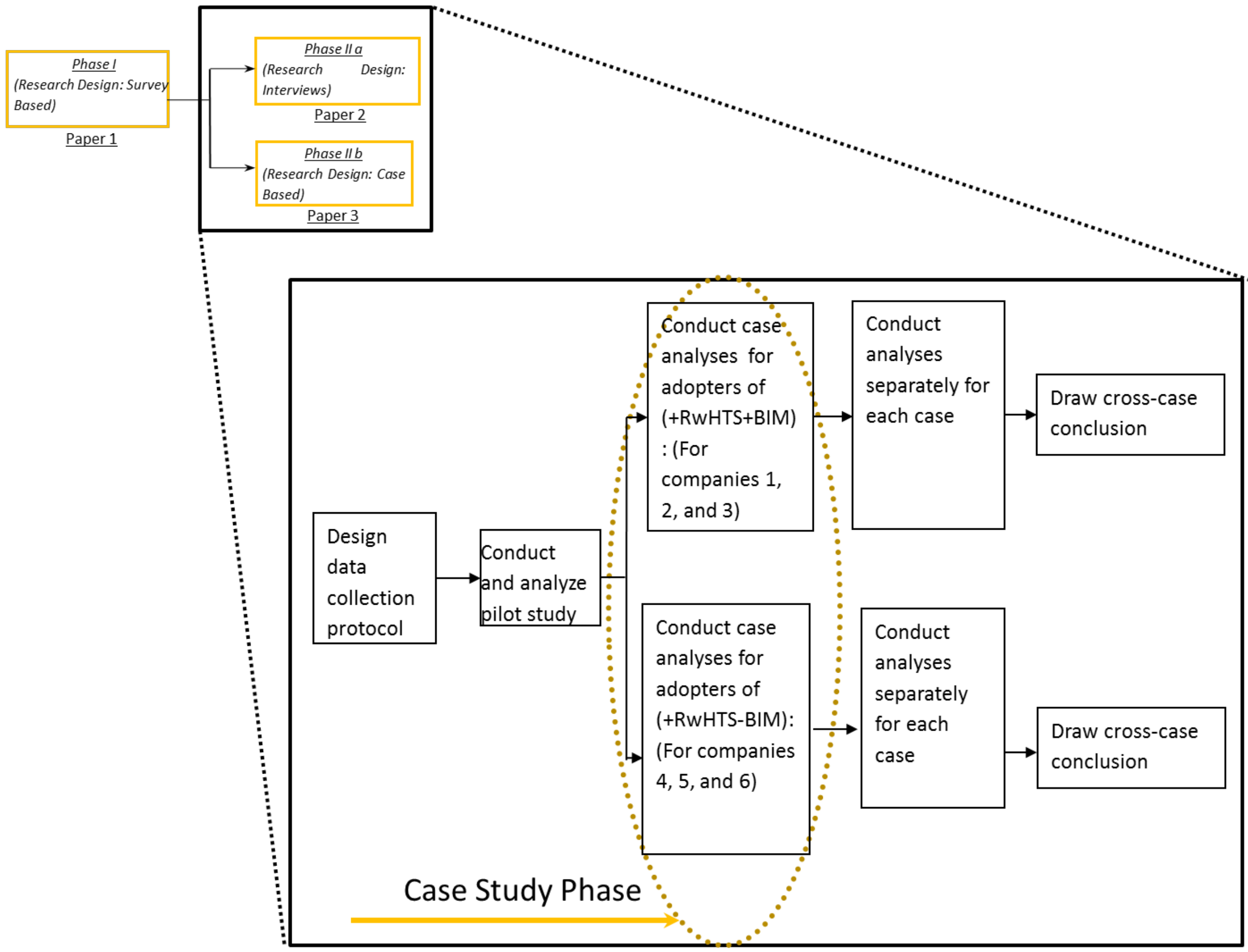


Figure 5.1: Research process (Developed from Yin 2009)

For this study, multiple case studies followed exact replication of the research design. The multiple case study approach was incorporated for each type of design firm. Protocols for conducting the study were established at the very beginning of this stage, which would act as the guiding document for the rest of the study. Questions were identified that intended to capture the information from the unit of analysis, which in this case was the participating organization. The questions were aimed toward gauging the general design process followed by the firms for the adoption of RwHTS in the context of green buildings. Additionally, other questions were aimed to understand the effect of BIM over the design process and the manner in which designers use BIM to enhance the acceptance of RwHTS.

The following techniques were utilized for analyzing the responses of the case interviewees to the questions:

- Process mapping the design process for the adoption of RwHTS, and identification of stages where BIM was implemented
- Video recording all the responses of the respondents, after their approval
- Manually noting all the information that was not converted into process maps.

After establishing the protocols, they were pilot tested to evaluate validity. The only difference between the pilot and the actual case study was the method in which the participating firm was selected. For the pilot study, the process of selection of the firm was based on convenience, access, and geographic proximity. This selection process based on the proximity and previous working relationship allowed for more prolonged and less structured relationship between the researcher and the pilot case respondents (Yin 2009). The recommendations by the respondents enhanced the quality of the interview questions. Upon the completion of the pilot study, the researcher conducted six site visits with the selected firms. Prior to conducting the site visit, contact with the firms was established via an email/telephone. An appointment was made to spend time with the principal designer of the firm to discuss the design process for the selection of RwHTS and other research questions. Prior to the site visit, the respondents of the study were made aware of the aims of the study which were as follows:

- Understand how buildings are generally designed by your organization.
- Understand the process of implementation of RwHTS at project level and whether the implementation changes the general design process followed.
- Ascertain the factors that affect the implementation of the shortlisted RwHTS.

The aim of the site visit was to understand the overall design process followed by the organizations generally and then for projects where RwHTS was adopted. The intention was to observe if there was any difference between the design process followed generally by the firm for green buildings and then for projects where RwHTS were implemented and investigate if such cases were treated as typical/atypical cases for the firm. All the information was compiled by means of process maps, video recordings, and taking notes. A process map was developed based on the information gathered from the participating designer(s) and then it was validated by asking them to review it through a process of member checking. If the process map was incorrect, then the corrections were applied and re-validated. However, if the process map for design at the organizational level stood validated, the focus was shifted toward evaluating the design process utilized at the project level and determining whether it remained the same. Thus, analyzing the design process adopted by the architectural firms and recreating it by means of process maps allowed a unique opportunity to define, analyze, and assess the highly fluid environment and incorporate boundaries. Additionally this process of analyzing data by the means of process mapping provided a holistic assessment in regard to the design of green buildings which included RwHTS. At the same time, it was agreed that all projects within the AEC industry are unique and are affected by factors such as expectation of stakeholders, project delivery, site specific constrains, code, and other. Based on this assumption, a more general process map was aimed for. Minor discrepancies in the process map were ignored if they were project specific, as it was agreed by the participants and researcher that design process in itself was very fluid and reactive to many factors that cannot be predicted or controlled at the beginning of the project. However, during the study it was ascertained that for most of the firms, a generalist process map could be developed as there was a certain consistency in the way buildings were designed by members of the firm. One major variable consistently found to be altering the general design process for most of the firms adopting RwHTS was the LEED certification of the project. According to most of the respondents, LEED certification of the building added certain steps, which otherwise would not have been included. Additionally, for the adopters of BIM and RwHTS, questions pertaining to the use of BIM and the level at which models were used was also asked. The researcher also asked how BIM was used to enhance the adoption of RwHTS and whether the adoption of BIM resulted in frequent adoption of RwHTS. The completion of the case study phase marked the end of the data collection from the six separate cases.

5.4.2 Analyze data collected

The main aim of this phase was to conduct analysis of the data collected. All the information from each case was noted separately. On the basis of the case-by-case analysis, the researcher noted the differences between the organization's design process and the way BIM was adopted across the firms adopting BIM. Also, differences in process maps were noted when the LEED certification was introduced. All the identified differences were backed with explanations obtained from the designer(s) during the data collection phase. All the information derived from case-by-case basis was then generalized to represent information of each category. Then the data collected was analyzed in the following order to address the research questions effectively:

- General process followed by the organization from project initiation to the completion of design process was mapped for the two categories.

- The differences in the two generalized sets of process maps were identified to indicate how designers use BIM differently
- Based on responses to the questions asked of designers, evaluate whether the adoption of BIM resulted in frequent adoption of RwHTS.

All the similarities and contradictions were noted, to be presented as a part of the results, which is discussed in the next section.

5.5 Results

This study identifies the design process followed by the architectural firms for private sector owners who intend to build green buildings that include RwHTS. This study also explored whether the adoption of BIM changes the way green buildings are designed and whether adoption of BIM results in frequency adoption of RwHTS.

5.5.1 Design process followed by the adopters and non-adopters of BIM

This section discusses the design process followed by the adopters and non-adopters of BIM for the design of the green facility. During this study, based upon the responses derived from the selected firms, it was realized that interviewed designers as a whole segregated the design process into four major phases for green buildings, which are:

1. Pre-design development
2. Schematic development
3. Design development
4. Construction documentation

However, the first two phases, pre-design and schematic design, could be integrated together into one major phase. This decision of adopting one or two phases was determined by the principal architect of the firm based upon size, complexity, owner project requirements, identification of unknowns (often termed as risks), and the LEED certification of the project. Figure 5.2 provides an overall layout of the phases followed by architectural firms, in general, for the design of a green building which adopts RwHTS.

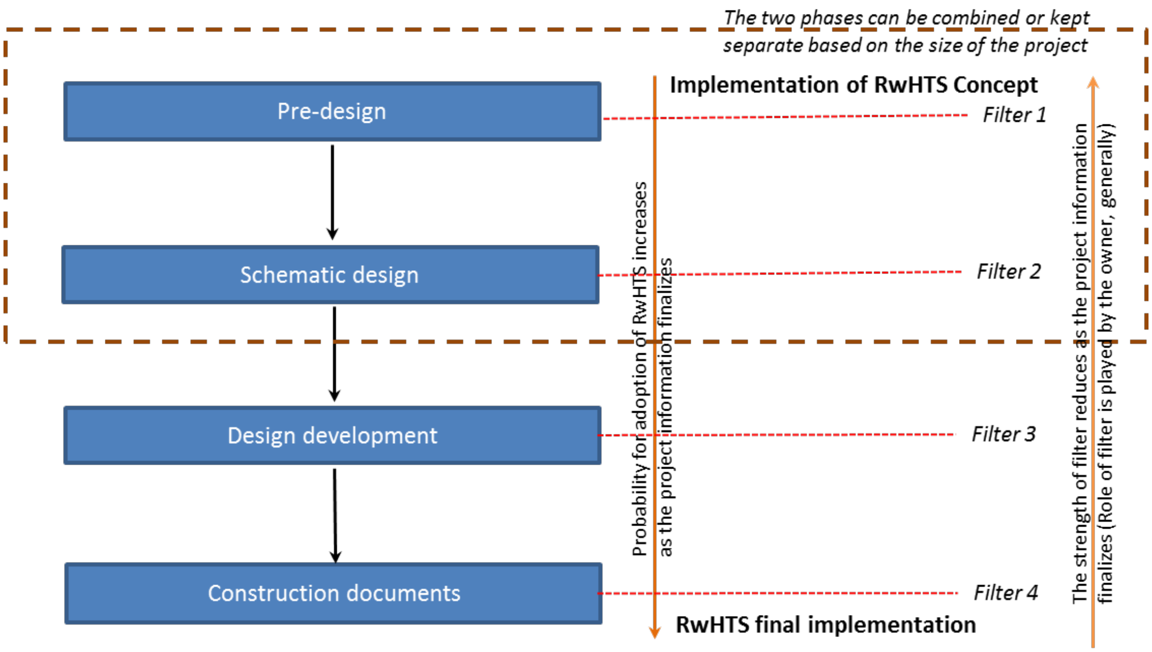


Figure 5.2: Overall design process followed by architectural firms, for the design of a green building which adopts RwHTS

It was also observed that LEED certification of projects added certain scope of work and a layer of complexity to the firms, depending on the familiarity with the process of LEED certification, thereby, adding certain steps which otherwise would not have been present for the design of the green building. These extra steps in the design process can be attributed to the fact that the green buildings require a certain amount of documentation for the strategies/technologies adopted. In addition, some respondents also reported that stakeholders needed to be educated about the LEED certification process for the building and the expectations from each of the stakeholders. The figure also depicts some general observations derived, which are as follows:

- Most of the sustainable strategies including RwHTS are decided on a broad level at pre-design phase.
- The probability for adoption of the strategies/technologies including RwHTS that survive initial filters are more likely to remain until the end increases.
- There is never a 100% probability for adoption of the strategies/technologies including RwHTS, until it's installed on site, due to the unpredictable nature of projects.

- The role of filter is played by the owner or the owner representative. This entity is similar to a gatekeeper who decides what moves forward at the end of each phase.
- The strength of this filter is reduced as the project progresses, generally, since a project moves across the various stages only after the approval of owner or their representative. Accordingly, the concepts to which the owner or representative objects diminish considerably as the project moves towards construction documentation.
    - Two different methods of iteration between the designers and other stakeholders were identified by participating firms: Closed loop iteration
    - Spiral iteration

Figure 5.3 depicts the closed loop and spiral iterations identified in this process. Both iterations were identified at the end of each phase and it was up to the designer to select one of the two iterations with the owner. In the closed loop, iteration design process doesn't move to the next phase until all the outstanding issues are resolved. As per the respondents, on an average, 2-4 iterations are required in the closed loop approach before progressing to the next phase, thereby resulting in time consuming process, but at the same time the iteration reduces the risk for the designer. On the contrary, in the spiral loop iterations, the changes were identified and the design process was continued, while simultaneously resolving outstanding issues. Although this reduced time associated with the design of the facility in comparison to the closed loop, spiral iteration increased the risk on the part of the designer.

All of these observations are discussed in detail with respect to the process maps in the subsequent section, and Figures 5.4 provides information about the design process followed by the participating architectural firms that are from the (+RwHTS-BIM) category. The figure also depicts the extra steps in blue color which are adopted by the (+RwHT+BIM) category

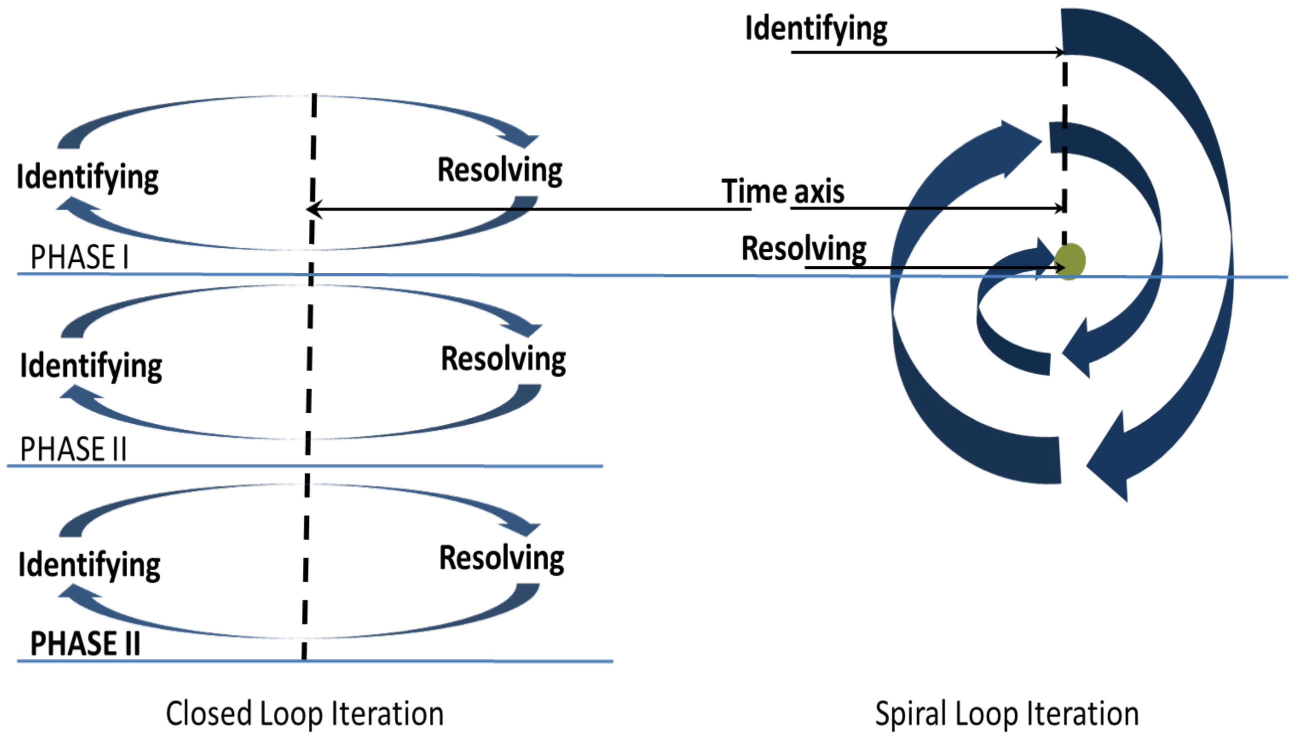


Figure 5.3: Closed loop and spiral loop iterations between designer and owner

5.5.1a Pre-design development

This is the first phase toward the development of the design. Figure 5.4a depicts the steps within this stage in detail with the help of process maps. This phase, as per the respondents, is also mentioned as the program development phase. This phase is generally employed for projects that are large, complex, or intend to be LEED certified. This phase generally involves the setting of goals for the green building, understanding the building program, owner aspirations, budget if ascertained, site if identified, and regulatory requirements. Understanding regulatory requirements becomes critical if the designer will be working with an unfamiliar geographical location. In addition, metrics for evaluating the success of goals set for the project are also finalized.

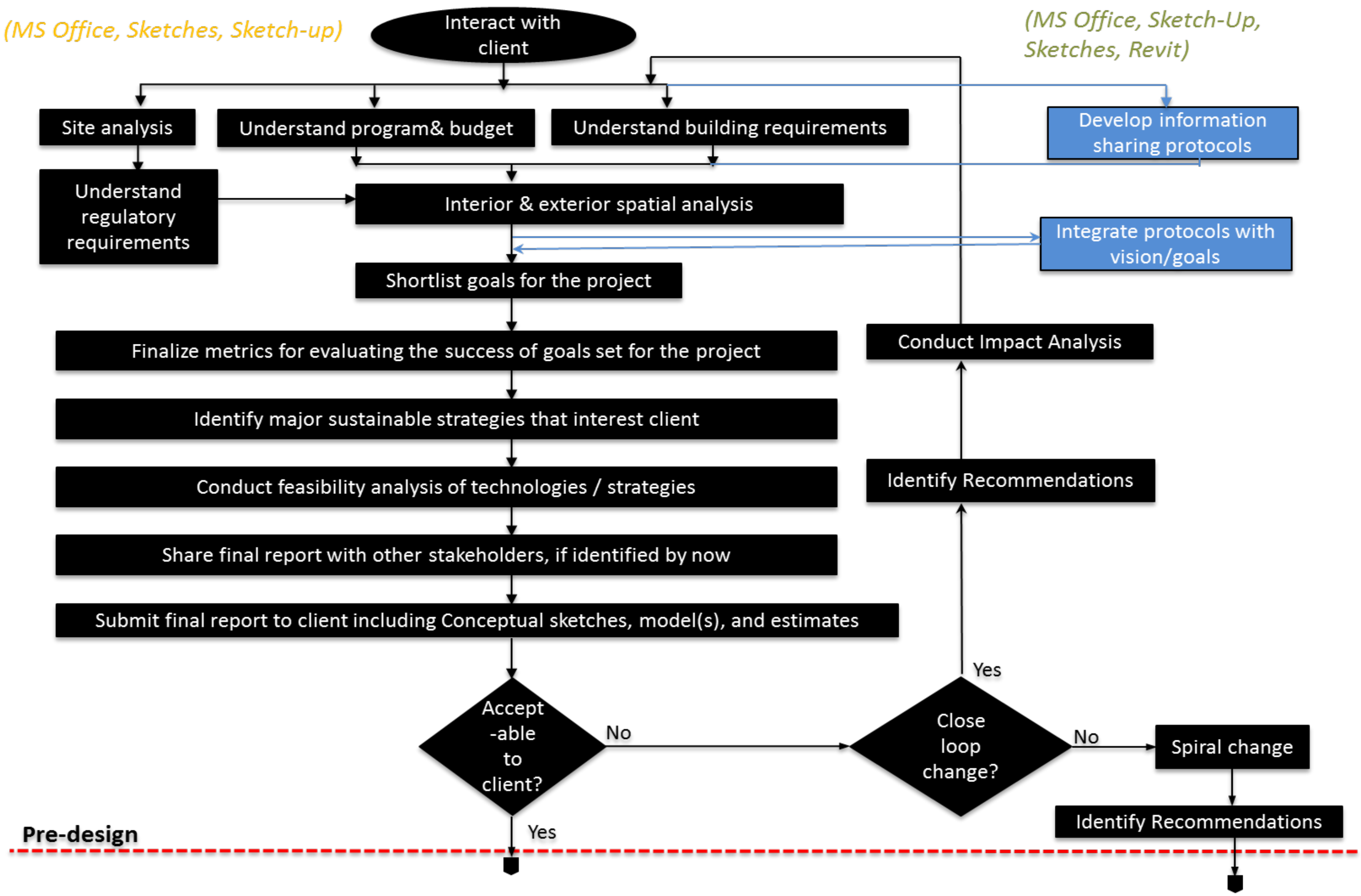
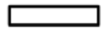


Figure 5.4: The design process followed by the participating architectural firms that are adopters of (RwHTS–BIM) superimposed by the (+RwHTS+BIM) in blue, for the predesign phase.

Table 5.1: Legend for Figure 5.4

Symbol	Explanation
	Start of the process map
	Process/task in the map
	Decision node
	Off-Page Connector

For a LEED project, this phase also involves a kick-off meeting which includes a charette. The intensity of the charette is dependent upon numerous factors. Some of the important factors are previous experience of stakeholders on LEED projects, previous working relationships between the owner or representative and designer, familiarity of owner/representative with the process of LEED, size or complexity of project, budget constraints, aspirations, and other factors. Hence, this stage involves considerable understanding on the part of the designer, and the clarity of this phase is critical as it lays the path for the design of the green building. In addition, major sustainable strategies are identified and feasibility analysis is also conducted. So for RwHTS, its adoption for the project would be decided at this phase. This phase outlines the goals and the metrics to evaluate the success of the design of the building. Towards the end of this phase, designers tend to produce a report that includes the mentioned goals, metrics for evaluation of success, a feasibility report, or site analysis. The report is then submitted to the owner or representative as shown in Figure 5.4a.

The owner or representative acts as a filter for all the information that is compiled and submitted for approval. At this stage, the owner can accept or recommend changes. This iteration of information, as shown in the previous section, can occur in two ways, namely: spiral or closed loop. For spiral iteration, the owner receives the report and recommends the changes, which are identified and incorporated in the future by the firm as the project moves to the schematic development stage. All the changes are achieved as the project progresses. In contrast, for closed loop iteration, the project does not move forward and the firm retracts to the previous steps, returning back to the middle of this phase to identify the recommendations of the owner and then again prepare a report for their approval. With closed loop iteration, the designers tend to continue in loops until owner approval is obtained on the report. Generally it was reported that this stage requires about 2-4 iterations. The firm only moves to the next phase, schematic development, when the owner approval is obtained. The closed loop approach was observed to be less common than the spiral approach, since the spiral approach allows the firm to progress on the project as changes to previous items are incorporated.

For the adopters of BIM, the design process was also the same. No extra step was reported, except for developing information sharing protocols for the use of BIM. In addition, all the site topographical information, if received at this stage, is converted into a digital format, which can be used by the designers for later stages. The creation of protocols for the use of BIM was not reported common among the firms interviewed, but still some responding architectural firms used it. Only one of the three firms mentioned the use of protocols and updated it if needed. The second company partially incorporated the use of information sharing protocols. In addition, most of the interviewed adopters of BIM require involving major stakeholders from the very beginning of the project, implying a high degree of integration from the earliest phases. In addition, adopters of BIM created a goals/vision statement for the use of BIM that compliments the overall goals of the sustainable facility. Certain designers interviewed during the case study were using BIM just as a presentation or visualization tool. Since the design has not begun, the use of tools by adopters and non-adopters of BIM was for the same purpose, although the tools were different. And, the use of different tools for different tasks became greater for non-adopters of BIM as the stages progressed.

This stage is important as it establishes the process of flow of information among the stakeholders, before BIM as a product can be utilized. The subsequent section discusses schematic development phase.

5.5.1b Schematic development

The schematic development phase is also termed as the conceptual design development phase. Figure 5.5 depicts the steps within this stage in detail with the help of process maps. This is the second phase for the design development of green buildings employing RwHTS. In cases where the project is small or simple, this phase tends to be combined with the previous phase. The designers generally, for this phase, tend to derive a conceptual design based on the information that they have collected from the owner/representative in the previous phase.

They generally use numerous concepts to start the project, based on all the compiled information from the previous phase. These concepts are generally in form of a package that contains sketches, spatial analysis, massing, bubble diagrams, and plans and a very generic level. The owner selects one or a few from various concepts/schemes on which the designer can work further. In addition, “ball park” estimates are also a part of the package. At this point of design, major sustainability strategies and technologies that affect other systems installed in the building are also identified. The ambiguity is still significant, but less than the previous phase, as the goals and metrics are used as a yardstick to realize the owner’s expectation.

For LEED certified projects, a charette or a meeting is again conducted toward the end of this phase to evaluate whether the project is continuing on the expected path for realizing its sustainability goals. Additionally, in this phase the type of sustainable strategies/technologies are shortlisted. In case of RwHTS, various types of RwHTS are shortlisted for the project. According to the respondents from both of the categories, various online calculators and decision tools are used to decide upon the implementation of RwHTS. The details pertaining to the specifics of the RwHTS like type/sizing/components are not decided at this phase. The output of this meeting also forms a part of the report that is submitted to the owner or representative toward the end of this stage.

Certain adopters of (+RwHTS+BIM) stated that they used the tools of BIM extensively to create presentations and used the aspects of visualization during this phase. At the same time there were some respondents who were adopters of (BIM+RwHTS), and felt that BIM still was not technologically competent enough to be used at this stage. Some of the tools, according to them, were not competent enough to handle complex structures. Additionally, most software requires a certain amount of detailed information which is not typically finalized by this stage, thus also creating a problem for the adopters of BIM. One respondent felt that BIM was a barrier toward creativity and limited the ability of the designers to explore the design. In addition, the respondent raised the issue of time associated with creation of sketches by hand versus using a tool such as Revit. The respondent felt that it was much easier and more effective to draw sketches than to draw the building using BIM tools as they felt that they were duplicating the information. Another respondent mentioned the concept of room model where it formed the basis of design. These room models were at the core of the design and the design evolved from those customized room models, which not only helped with the visualization aspect of the project at this stage, but also during later stages of the design. One can associate this concept to the design philosophy of “*part to whole*.” But again, this concept is dependent upon the project and is not used universally across the projects.

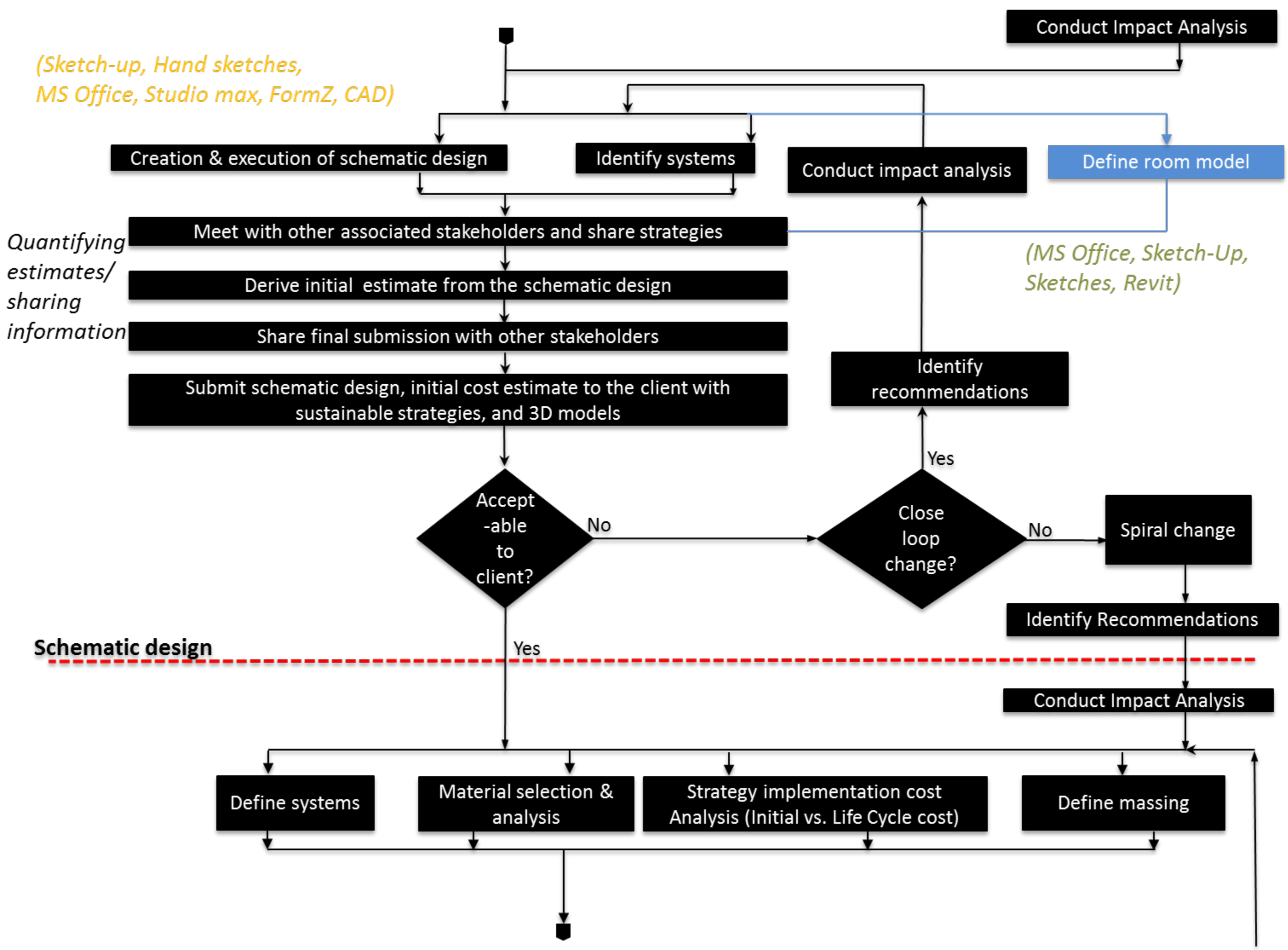
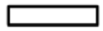


Figure 5.5: The design process followed by the participating architectural firms that are adopters of (RwHTS–BIM) superimposed by the (+RwHTS+BIM), for the schematic design and design development phase.

Table 5.2: Legend for figure 5.5

Symbol	Explanation
	Start of the process map
	Process/task in the map
	Decision node
	Off-Page Connector

Toward the end of this phase, another report is submitted to the owner that has sketches, spatial analysis, generic plans, and 3D models along with a “ball park” estimate of the building. As discussed in the previous section, the owner or representative acts as a filter for all the information that is compiled and submitted for approval. At this stage, the owner can accept or recommend changes. This iteration of information, as shown, can occur in two ways, namely: spiral or closed loop, depending on the method that the design firm prefers. Generally, it was reported that this stage requires approximately 4 iterations, as the designer tries to confirm the concept for the project. Approval by the owner or representative of the project concept marks the end of this phase, and the next phase, design development, can be started.

5.5.1c Design development

The design development phase involves creating the design for the building. Figure 5.6 and Figure 5.7 depict the steps within this stage in detail with the help of process maps. Along with finalizing the design, the designer also finalizes the sustainability strategies/technologies including the RwHTS that can be adopted for the project. Various analyses are developed and considered, such as life cycle analysis for the selection of specific sustainability strategies/technologies. In regard to RwHTS, depending upon the type of RwHTS, specific consultants are engaged. The decision on the specifics of the RwHTS, such as the type/size/location/use is nearly finalized in this stage. Non-adopters of BIM mentioned that they used online calculators or company customized calculators for the finalizing of RwHTS. The adopters of BIM also mentioned the use of tools, such as online calculators or excel sheets for deciding details about the RwHTS. However, at the same time, certain adopters of BIM admitted that the market lacked a dynamic RwHTS tool that was interoperable with the exiting BIM tools used by the designers. Generally in this phase, other stakeholders such as engineers, apart from the owner or owner representative, become actively engaged in providing inputs for the designed building. This stage of the project is highly collaborative with other stakeholders in comparison to the two previously mentioned stages. The designer also finalizes the building materials in collaboration with other stakeholders, generates a schedule for the project, and ensures that the recommended strategies and technologies fall within the allowable regulatory requirements of the building. If required, the designer also meets with the regulatory officials for any clarification of the requirements. With the incorporation of the mentioned steps, the scope for the design of the building is further refined. Additionally, the budget of the project is further refined and any escalation in the approved budget is duly reported to the owner. Some designers submit the design to the owner upon 50% of completion, whereas others submitted upon 100% of completion - there was no consensus that could be achieved in this regard among interviewed firms. Upon 100% of completion of the design, some designers prefer to submit their projects for design review, in case the project is intended to be LEED certified.

For the adopters of (+RwHTS+BIM), many types of software are available at hand, including Revit or ArchiCAD for drafting the design. Other stakeholders associated with the project tend to use the information generated with this software to conduct energy, day-lighting, structural, and systems analysis of green buildings. There is a lot of "back and forth" of information in this stage of the project. If contractors are involved in this stage, they also evaluate the constructability of certain strategies and technologies and make recommendations to improve constructability. While the drawings are being constructed, model validation is concurrently conducted by the designers. At the end of this stage, a package is submitted to the owner or owner representative. However, prior to final submission of the package, a final model validation is conducted. The package contains plans, elevations, sections, 3D models, refined budgets, and other engineering analyses conducted for the project. The owner or representative acts as a filter for the entire package that is compiled and submitted for approval. At this stage, the owner can accept or recommend changes. However, it was pointed out by the respondents that the recommendations by the owner were typically less at this stage since the level of ambiguity was considerably reduced, and since many ideas had been evaluated and discarded in earlier phases. This iteration of information, again as shown, can occur in two ways, namely: spiral or closed loop, depending on the method that the design firm prefers. The approval by the owner or representative step marks the end of this phase and the next phase can be started, where the construction documents are developed.

5.5.1d Construction documentation

By the beginning of the construction documentation phase, selection, design, and analysis of all the design and sustainability strategies and technologies are finalized, apart from the ones that might have been eliminated at this/prior stage due to multiple reasons such as cost, complexity of the proposed system, in some cases client changing perspective, and others. Figure 5.7 depicts the steps within this stage in detail with the help of process maps. The main aim of this stage is to create documents that assist the contractors and fabricators in the construction of the building which meets the accepted design. Specifications are also generated and finalized in this stage. Depending upon the project delivery, final package is shared with the contractor for review and the document is changed if there are any constructability issues identified with the document. The designer at this stage further refines the budget and the budget is expected to be mostly accurate.

For the adopters of (+RwHTS+BIM), many types of software are available at hand, including Revit or ArchiCAD for drafting the design. The designer collaborates with the general contractor, and depending upon the agreed upon information sharing protocols and project delivery, the contractor is involved and the information is shared with the general contractor. Software, such as NAVISWORKS, Revit, and ArchiCAD, are used by the contractors and the information exchange is shared via a secured server. The next section discusses the use of BIM for the adoption of the RwHTS.

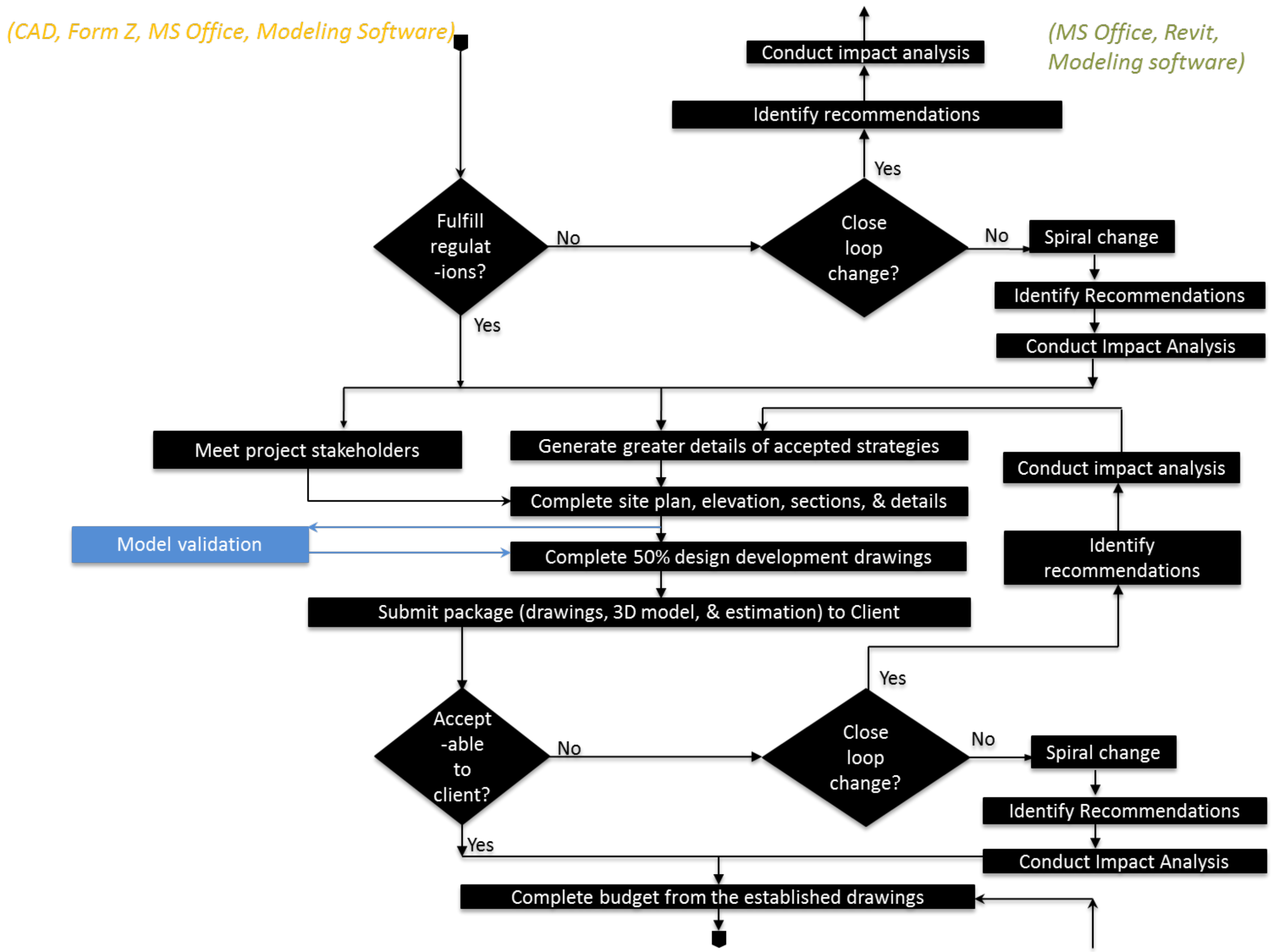


Figure 5.6: The design process followed by the participating architectural firms that are adopters of (RwHTS–BIM) superimposed by (+RwHTS+BIM), for the design development phase.

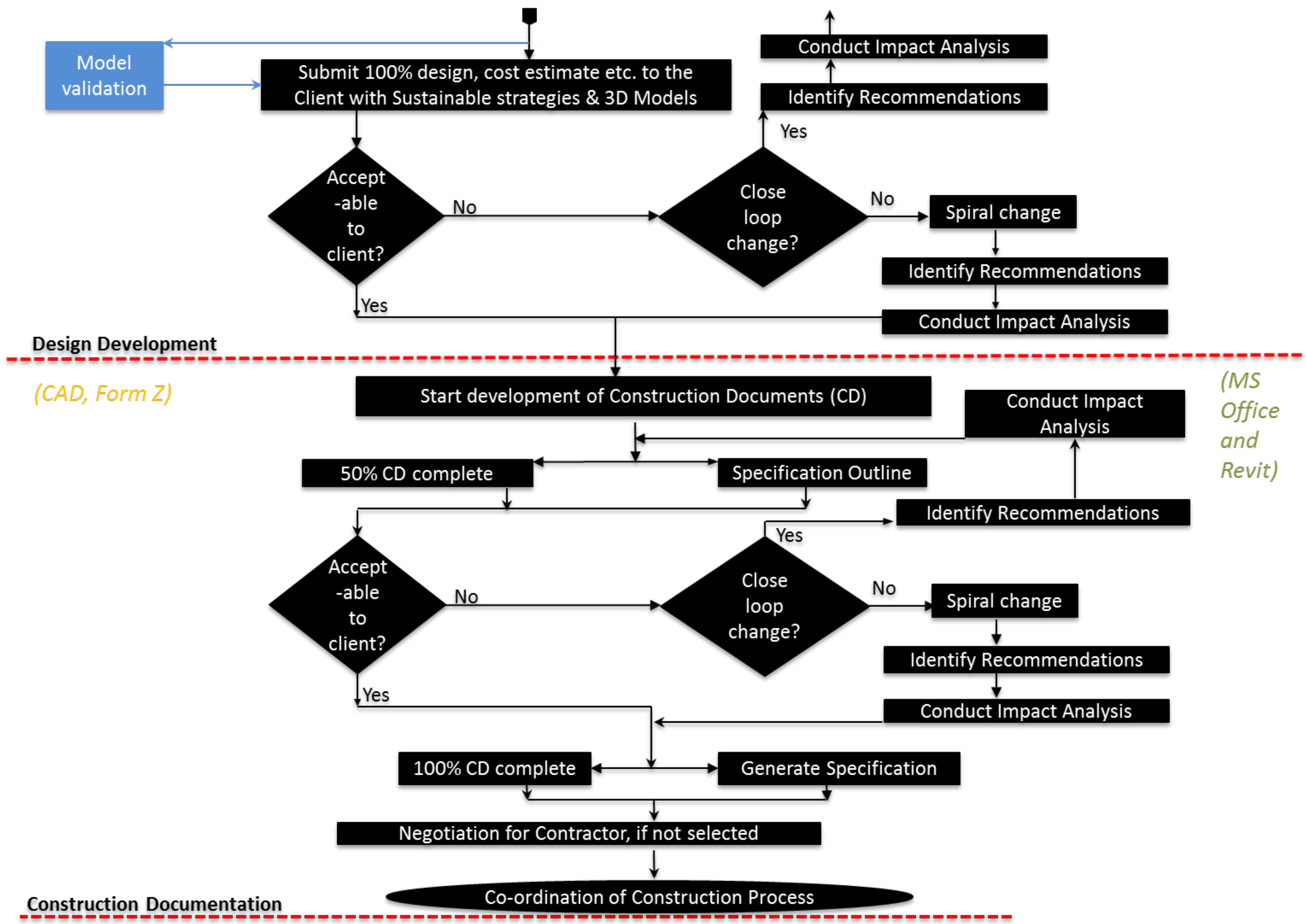
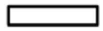


Figure 5.7: The design process followed by the participating architectural firms that are adopters of (RwHTS–BIM) superimposed by (+RwHTS+BIM) for the design development and construction documentation phase

Table 5.3: Legend for figure 5.6 and 5.7

Symbol	Explanation
	Start of the process map
	Process/task in the map
	Decision node
	Off-Page Connector

5.5.2 Impact of BIM upon RwHTS

The study also found that BIM at the current level of use does not significantly encourage the adoption of RwHTS. Many other important factors including code, cost, regulatory requirements, and others were reported by interviewees to determine the adoption of RwHTS for a particular project. This conclusion was validated when all of the BIM adopting firms responded negatively when asked if BIM causes the adoption of RwHTS. The way in which BIM is used currently allows more effective visualization and collaboration, but other factors as mentioned previously also play an important role. It was also unanimously mentioned by stakeholders that any RwHTS that might have been considered for adoption in the initial stages of the design process can be discarded even at the construction documentation stage, primarily due to cost associated with the adoption of these systems – RwHTS are prime candidates for elimination due to budgetary constraints.

Although all the respondents from both of the categories mentioned that they always recommend RwHTS to their clients, factors such as code, initial cost, payback period, operation and maintenance issues, and inability to quantify savings on a dynamic basis were reported as major barriers for the adoption of RwHTS. In addition, one of the adopters of BIM also reported that the tools to quantify the savings generated from rainwater were very basic and were not parametric and interoperable with the software the designers in the particular office used. They recognized the need for a tool that was more dynamic in nature and was based on precise weather data. In addition, it was also agreed that industry in general is still coping with the use of BIM as a decision and parametric tool, due to numerous factors such as direct and indirect cost of implementation, liability, interoperability, risk, proficiency, and other factors. At the same time, however, adopters of BIM also reported following advantages of using BIM:

- There is a reduction in redundancy of work by multiple stakeholders. Only one model is developed from the very beginning and the stakeholders contribute towards its development as the project progresses in time.

- Various stakeholders can work on the same model together thereby enhancing the collaboration among the stakeholders.
- The software reduces the clearly established distinction between various major stages of project. Lines depicting clearly demarcating phases was blurring unless specified by the owner.

Hence as an overall observation, not many differences were observed in the design process for green buildings between adopters of BIM and non-adopters of BIM, apart from the advantages cited above. For one of the three (+RwHTS+BIM) the only significant difference was the way BIM was used, and that was as a tool. The other two had started to use certain aspects of information sharing. Even during the interviews, when asked if BIM enhanced the acceptance of RwHTS, the response of designers was negative. The reason for it is as follows:

- The decision to adopt RwHTS involves calculations are perceived to be relatively simple, unlike energy or day-lighting analysis, which however is not the case.
- The online tools available to design RwHTS are not parametric with the software used by the architects. And some of the designers in the architectural firm feel frustrated about problem.
- Lack of a precise interoperable RwHTS software which could link with the tools used by the designers.
- Some of the adopters of BIM were uncertain how BIM could be effectively used to design and support decisions regarding RwHTS on their projects.

5.5.3 Conclusion

Thus, this study was able to generate process maps depicting the design process used for the creation of green building that used RwHTS. The study found that not many differences were observed in the design process for green buildings between the categories of (+RwHTS+BIM) and (+RwHTS-BIM), apart from the advantages of higher visualization, collaboration, time savings, and communication for the firms representing the (+RwHTS+BIM) category. The participating firms were selected purposively and were a part of (+RwHTS+BIM) and (+RwHTS-BIM) type. In addition, the study was able to identify that the adoption of BIM has no effect on the adoption of RwHTS. There were numerous reasons for such an occurrence and have been discussed in the prior section.

The next section discusses the limitations and the future research that this study has generated.

5.6 Limitations

There were certain limitations that this study faced. First, green buildings can be designed using different contractual methods and each contractual method has a certain difference than the other. The design process depicted in the paper represents only the general design process developed based on a synthesis of the six firm-specific design processes. Further studies need to be conducted to establish the generalizability of the process maps. Additionally, the design process is prone to variables such as relationship among stakeholders, project delivery, contractual mechanisms shared between stakeholders, and others. Future research should account for these factors which can significantly influence the details of the design process overall. In addition, design process generated in this research could vary as per the contractual methods with which a project is designed and constructed.

Also, alternative approaches such as the Delphi or direct observation method could be used to verify the outcomes of this research. However time investment of time on the part of participants can be an issue. This study identified the design process followed by designers to design a green building and generated a common process map that was representative of the processes mentioned by case study participants for projects in which RwHTS were adopted. The identified design process for the both the categories (+RwHTS+BIM) and (+RwHTS-BIM) can be applied to other green projects that involve the adoption of sustainable strategies and technologies. However, this has not been tested and can be a potential for a future research.

The respondents for this study were purposively selected on the basis of level of adoption indicated by the respondents provided in the survey conducted previously. The respondents of the case study were assumed to be the experts in the areas of RwHTS and BIM due to the level of adoption represented in the survey. However, apart from the level of adoption, the participants were not tested on the level of expertise. There is a possibility that some of the participants could not have been the experts of the category that they were representing.

5.7 Future research

This section discusses the future research areas that have been generated by this study. A descriptive study could be conducted as a follow-on to analyze the process devised from this study to see whether it can be further validated. The study also investigated adoption patterns of BIM within design firms and attempted to determine whether there was any relationship between the adoption of BIM and RwHTS on projects. The study found that the adoption of BIM did not necessarily ensure or encourage the adoption of RwHTS at this time. It may instead be the case that it was the innovativeness of the adopting unit (the design firm) that led to the adoption of RwHTS in projects. However, further studies need to be conducted to validate this indication. Multiple reasons identified by the researcher in the previous section may also affect the role of BIM in adoption of sustainability technologies and strategies in capital projects at this point in time. However, at least in theory, BIM does possess the capability to influence the adoption of sustainable innovations due to factors such as ability to enhance visualization, collaboration, etc. among the stakeholders.

Two of the three non-adopters of BIM reported that the decision to adopt RwHTS was relatively simple currently and did not require complex analysis tools to decide on adoption. Also as per the respondents, the market does not presently offer software for RwHTS simulations that takes into account the complex changes in weather patterns that have been recently observed, meaning that simple tools presently available do not offer the ability to accurately predict system behavior. McGraw-Hill (2010) conducted an analysis on the adoption of Green BIM and identified the need of intelligent water simulation tools. Thus simple tools accounting for historical data can no longer be the sole baseline for the decision, as the climate is no longer predictable as per the historical data. Hence, decision tools for RwHTS available need to be analyzed to identify if the problem exists. Also investigations should be conducted to understand how connected the existing software tools are with the weather models. The importance of weather models is highlighted by the fact that they are required to provide more accurate performance forecasting, considering the requirements for RwHTS such as first flush, containment size, rain frequency, and others that can contribute towards the success/failure of RwHTS. As the need for alternative water resources becomes increasingly dire due to climate change and increased human demands, the need for accurate performance modeling of RwHTS will also increase. Also, the need for such a tool is highlighted with the fact that generally the systems adopted in a green building are integrated with other systems. Hence, an inefficient system of one type can also affect the efficiency of other connected systems. In addition, the respondents from (+RwHTS+BIM) category not only felt the same but also felt that these tools were not interoperable/dynamic with the software used currently by the associated stakeholders.

During the study it was identified that the designers tend to propose strategies in early design phases for consideration by owners, but ultimately, owner/owner representatives filter along the course of the project, as observed in the design process map. Hence, it raises an interesting question as to “who is the ultimate adopter?” Thus, another future research would involve an investigation into more meaningful roles of design firms in the adoption of sustainable strategies. The role assumed by the designer in sustainable projects, i.e. “recommender” or “champion,” needs to be investigated further

Various contractual methods also have the potential to change the general design process developed for a green building which adopts RwHTS; the design process generated could vary as new contractual methods are introduced. Future studies should take into account the variation in design resulting from differences across contractual methods. In addition, future research could also be conducted to understand whether properly engineered systems are less likely to be value engineered in comparison to other/generic systems. Furthermore, future studies can also identify whether BIM allows potential adopters to adopt complicated systems.

The design process developed in this study depicts the manner in which a sustainable strategy gets adopted on a generalist level. However, the process is not necessarily generalizable to other types of sustainability strategies and does not involve the technical details about any particular RwHTS. Adoption of a RwHTS has certain parameters which are specific to the particular context of adoption, and use of one strategy or technology may influence the feasibility of related strategies and technologies. Future research should further explore the relationships among adoption of different complementary technologies and strategies as part of understanding their adoption.

5.8 Contributions

This section identifies contributions made to the existing body of literature and which are as follows:

- The study also investigated the differences in process to design a green building between firms that are adopters of (RwHTS +BIM) and (RwHTS–BIM).
- The study also identified current ways in which BIM is adopted by the participating architectural firms
- The study further investigated the role of BIM in encouraging or facilitating the adoption of RwHTS in green buildings. While in previous studies (see Chapter 3), a moderate relationship

was observed between the adoption of RwHTS and BIM, when interviewees were personally asked about the relationship between BIM and RwHTS, no relationship was explicitly identified in this study.

Chapter 6: Validation, Conclusion, Contribution and Future Research

The first five chapters of the dissertation have explored the importance of observability for the adoption of RwHTS and depicted how designers use BIM to enhance the acceptance of RwHTS, resulting in frequent adoption of RwHTS. For this research, from the beginning of the study, there was an underlying assumption that BIM enhances visualization which has been linked to observability, and therefore if BIM is used for the design of green buildings, it would result in frequent adoption of RwHTS in green projects. In order to answer the question, numerous interim questions also needed to be answered and required an mixed research design approach including both quantitative and qualitative data. The first phase of the research employed a survey methodology involving quantitative research. In contrast, the second phase of the research involved holistic multiple case study methodology, which was primarily qualitative research. Thus, the outcomes of the research were both qualitative and quantitative in nature. For any research to be complete and effective, it needs to be validated, make contributions to the existing body of literature, and generate avenues for future research by humanity. This chapter concisely discusses the validity of the study, conclusions, contributions to the existing body of literature, and avenues in which extensions of this research can be carried out for each of the research questions identified at the beginning of the study. Subsequent sections of this chapter discuss each of the following questions in turn:

1. What are the trends for implementation of RwHTS and BIM among designers in the southeast US?
2. Does observability play an important role in the adoption of Rainwater Harvesting Technologies and Strategies (RwHTS)?
3. How do designers use Building Information Modeling (BIM) to enhance the acceptance of RwHTS? As per literature, BIM enhances visualization and visualization has been linked with observability, so does the use of BIM result in frequent adoption of RwHTS?

6.1 What are the trends for implementation of RwHTS and BIM among designers in the southeast US?

6.1.1 Introduction

This research question aimed to identify the implementation patterns for the adoption of BIM and RwHTS among the designers in the southeast coast of US. As mentioned in Chapter 3, Rainwater Harvesting Technologies and Strategies (RwHTS) were defined as the technologies/strategies used for the permanent collection of rainwater within a given building, so as to enhance the groundwater table of the area, and avoid storm water runoff and complications associated with it on the ecosystem. In addition, the study tested certain hypothesis and identified if any relationship could be derived between the implementation of:

- RwHTS and BIM
- RwHTS/BIM implementation and firm size
- RwHTS/BIM implementation and firm experience
- RwHTS implementation experience of firm with federal projects

6.1.2 Point of departure

Studies on rainwater harvesting have depicted how RwHTS can reduce dependence on aquifer resources and contribute towards resolving the increasing societal and economic water demands across the globe (Jyothiprakash and Sathe 2009; Sivanappan 2006; Sultana 2007). At the same time, they can become complex, depending upon numerous factors such end use of conserved water, the complexity associated with project type, tank size, site, collection, transportation, and weather (Angrill et al. 2012; City of Bellingham 2012; Chatfield and Coombes 2007; Ibraimo and Munguambe 2007; Jothiprakash and Sathe 2009; Levario 2007; Mun and Han 2012). In order to reduce the complexity of green projects, BIM offers functions such as enhanced visualization, data management, and higher collaboration. These functions reduce the complexity associated with the adopted sustainable systems, by enabling the potential adopters not only the capability to view the innovation but also evaluate the performance and benefits of the innovation with regard to the facility and then share the outcomes with all the direct stakeholders of the project. BIM has been found by researchers to have the potential to positively impact the adoption of sustainable technologies (Azhar et al. 2009; Sidduiqui et al. 2009).

Multiple studies have been incorporated in the past five years to identify the BIM implementation globally by the stakeholders associated with the AEC industry (Ku and Taibet 2011; Luthra 2010; McGraw-Hill 2009; McGraw-Hill 2010). Based on this review, a study is deemed as required to address the current implementation patterns for RwHTS and BIM by architectural firms within the United States and identify relations between BIM and implementation of RwHTS; especially when multiple researchers have pointed out that BIM has the ability to facilitate in green building design. Furthermore, in order to understand the implementation patterns of RwHTS and BIM, current use trends in these technologies and strategies need to be identified. Further insight is also needed regarding the characteristics of architectural firms that are innovative in their use of RwHTS and BIM. In addition, architects/designers are involved from early stages of project feasibility to define a program, choose the site, and provide expertise with associated tasks (WBDG 2012b), and it is precisely at this phase when sustainable strategies (RwHTS in this case), along with BIM, have the potential to be considered for use on the project.

6.1.3 Validity

Validity is an important aspect for a research that determines the strength, confidence, accuracy, and applicability of the study. It has been defined as "*the best available approximation to the truth of a given proposition, inference, or conclusion*" (Pearce 1999; Trochim 2006). For the first research question quantitative research method was used involving a survey methodology to evaluate the use of BIM and RwHTS among design firms as a population.

6.1.3a Credibility

Credibility has been defined as "establishing that the results of the research are credible or believable from the perspective of the participant in the research" (Trochim 2006). As indicated in Chapter 2, the participants were selected on the basis of responses provided to the survey. The researcher did not have any previous working relationship with any of the respondents, which helped to avoid any bias. The sorting was done by respondents separate from one another on separate days.

6.1.3b Transferability

Transferability has been defined as *"the degree to which the results of research can be generalized or transferred to other contexts or settings"* (Trochim 2006). This is somewhat similar to external validity, which is defined in quantitative research. As explained in Chapter 3, multiple parallels were drawn between the demographics of the survey conducted by AIA (2009 and 2012), thereby establishing the generalizability for the study.

6.1.3d Confirmability

Confirmability has been defined as the "*degree to which the results could be confirmed or corroborated by others"* (Trochim 2006). The results derived from the study were somewhat similar to some recent studies conducted for the sustainability innovations in regard to the attributes of innovation. Recent studies indicate that visualization, a function of BIM, is most implemented by the adopters of BIM (McGraw-Hill Construction 2009).

6.1.4 Conclusions and limitations of the research

The study found that active RwHTS are adopted more than passive RwHTS and visualization is the commonly adopted function of BIM by the responding designers. The study also found that size of firm has a significant relationship with the Implementation of innovation (BIM and RwHTS) than the firm experience. In addition, the study found that BIM and firm experience shared a moderate relationship whereas RwHTS implementation shared a weak relationship. Furthermore, no relationship existed between the implementation of RwHTS by an architectural firm and its previous experience with federal projects, where resource efficient buildings have become a requirement. Lastly, a moderate relationship was observed between the implementation of RwHTS and BIM.

6.1.5 Contributions and Benefits

This section identifies contributions made to the existing body of literature, as follows:

- Passive RwHTS are adopted more than Active RwHTS.
- The number of firms reporting having adopted at least one feature of BIM was lower than the number of firms reporting implementation of at least one type of RwHTS.
- The study also found that firm size has a stronger relationship with the implementation of innovation (BIM and RwHTS) than the firm experience.
- The study found a moderate relation between the implementation of BIM and RwHTS.

In addition, during the selection of RwHTS, the study also depicted the current adoption patterns of RwHTS. As per these patterns, RwHTS that were more commonly adopted by architectural firms were identified. Various stakeholders such as owners, and manufacturers associated with the construction of green buildings, would benefit by this identification. The owners will be able to identify the commonly adopted RwHTS by the designers and manufacturers can identify the adoption pattern of their product with respect to other RwHTS (e.g. Manufacturer of extensive green roof can observe the adoption with respect to intensive green roof and this stands true for above and below ground storage tanks).

6.2.6 Future research

This section identifies the areas which need further research, or avenues of research that were opened because of this research.

The respondents of the study were designers/architects geographically located along the southeast coast of the United States. This study also tested that passive RwHTS are adopted more than active RwHTS, and found it to be correct. However, the design of the study did not establish the reasons that underlie the difference, since the process of implementation was outside the scope of the survey. A future study could further explore the factors that encourage or discourage implementation. Additionally, investigation needs to be conducted to ascertain why there is a disparity between the implementation of retention ponds, which tend to have lower impacts on the environment than other strategies. Investigation needs to be conducted to ascertain whether the design industry is moving toward implementation of natural systems. Such systems not only interact with the human designed environment such as buildings, structures, and others, but also have a lower impact upon the place where they are implemented in comparison to the conventional strategies.

The study found that design firms used BIM least for municipal compliance and facility management. The reason for lower use in municipal compliance can be attributed to the fact that either officials do not require electronic submissions from design firm(s) or interoperability issues exist between the software used by the design firm and municipal office. In addition, from the results there is also an indication that the benefits of creating BIM models are not currently transferred to the owner. However, this is just an assumption based on the responses. A counter argument for the lower use of models for facility management can be that the contractors at times act as model coordinator prior to and during construction and updates the model upon completion of project. And upon completion of the project, the model is submitted to the owner by the contractor. However, future investigations need to be conducted in both areas to identify:

- Firstly, are the municipal offices across the nation capable enough to handle such models so that these are not the barriers and can pave the way for a global exchange of information?
- Secondly, are the benefits of creating a BIM model always transferred to the owner? Additionally, a BIM model can provide numerous benefits to the owners/facility managers over the lifecycle of the facility, although barriers exist to the effective use of BIM by owners, including training of facility managers, lack of previous experience, initial cost associated for the purchase of necessary software and hardware, maintenance of the model, and others. This aspect demands more detailed investigation, including identification of factors that act as barriers for the use of models for the purpose of facility management.

6.2 Does observability play a critical role in the adoption of selected Rainwater Harvesting Technologies and Strategies (RwHTS)?

6.2.1 Introduction

This research question aimed at determining whether observability, one of the five attributes of innovation, played a critical role in the adoption of RwHTS. As mentioned in Chapter 4, observability was defined as the degree to which an innovation and its results are visible to others

6.2.2 Point of departure

Attributes of innovation have been found to be important toward enhancing the adoption of innovations (Atun and Sheridan 2007; Black et al. 2001; Habets et al. 2006; Rogers 2003; Scott et al. 2008). Most of the studies conducted in this realm point to various attributes other than observability (Askarany et al. 2007; Black et al. 2001; Habets et al. 2006). However, what has not been identified until now is how observability as a single attribute enhances adoption of RwHTS amongst designers. Hence, the study tested whether observability played a critical role in the adoption of RwHTS in comparison to the other four attributes of innovation identified in literature, based on the number of decision factors classified by designers as relating to observability and the relative importance assigned to those factors. The study also created a mapping between attributes of innovation and specific design factors associated by designers with the adoption of RwHTS. Although owners are able to enhance innovation adoption in construction in a number of ways (Blayse and Manley 2004) and can sometimes be champions for sustainable innovations. However as discussed in chapter 3 most of the RwHTS are technical or complex in nature. Designers are an integral part of the project from conceptualization to completion for typical projects. So, it is imperative to determine whether observability plays a critical role in the adoption of the RwHTS, from the perspective of designers.

6.2.3 Validity

Validity is an important aspect for a research that determines the strength, confidence, accuracy, and applicability of the study. It has been defined as "*the best available approximation to the truth of a given proposition, inference, or conclusion*" (Pearce 1999; Trochim 2006). This research question involved quantitative research methods. The participants for this phase were shortlisted from the set of respondents who were a part of the phase I. In order to determine the validity of the whole process, credibility, dependability, transferability, and confirmability were used as validation strategies (Trochim 2006).

6.2.3a Credibility

Credibility has been defined as "establishing that the results of the research are credible or believable from the perspective of the participant in the research" (Trochim 2006). As indicated in chapter 2, the participants were selected on the basis of responses provided to the survey. The researcher did not have any previous working relationship with any of the respondents, which helped to avoid any bias. The sorting was done by respondents separate from one another on separate days. In addition, the factors which were ranked were actually derived as a comprehensive list from the respondents and many of the factors were mentioned several times by the respondents. Also, during the sort, the respondents were free to exclude any factor that they felt was not relevant. Furthermore, as indicated in chapter 4, all the process-related information that was collected was validated by the respondents prior to analysis.

6.2.3bTransferability

Transferability has been defined as *"the degree to which the results of research can be generalized or transferred to other contexts or settings"* (Trochim 2006). This is somewhat similar to external validity, which is defined in quantitative research. For this question, interviews along with the pile and quick sort methods were used to derive the results for this study. All three methods have been actively used in the realm of social sciences, and the methods were adapted to this domain to compliment the research question. The adapted methods were pilot tested to ensure the validity of the tools. Part of the case study was used to identify the factors critical for the adoption of RwHTS. Then, the identified factors were subjected to pile and quick sort by the respondents to order and rank identified factors. Every time a sort was completed, it was validated by the respondent to enhance the validity.

6.2.3c Dependability

Dependability can be defined as "*the ability to replicate the results over and over again*" (Trochim 2006), implying the same results would be observed if we could observe the same thing twice. The major area where this could be measured was in the areas of pile and quick sort. For pile sort, most of the identified factors were able to be classified according to attributes of innovations, apart from some identified exceptions which may suggest that additional attributes of innovations remain to be discovered. There were certain instances of lack of consensus during the mapping of factors that affect the adoption of RwHTS over the attributes of innovation. This could be either due to differences in design and project delivery methods for different firms and different projects However this assumption is only based on the notion that the respondents were unable to achieve a convergence.

6.2.3dConfirmability

Confirmability has been defined as the "*degree to which the results could be confirmed or corroborated by others"* (Trochim 2006). The results derived from the study were somewhat similar to some recent studies conducted for the sustainability innovations in regard to the attributes of innovation. Recent studies indicate that the success of any product in market depends upon many factors including approval from regulatory bodies (McCoy 2008), which was supported by the study.

6.2.4 Conclusions and limitations of the research

The study found that observability was not an important factor with the adoption of the selected RwHTS, which is congruent with previous studies conducted in the literature. Compatibility for (+RwHTS-BIM), and compatibility and relative advantage for (+RwHTS+BIM) were identified as the important attributes that determined the adoption of RwHTS. As per McCoy (2008), the success of any product in the market depends upon regulatory resistance and approval from regulatory bodies, which in this case is code. The results of the factor rankings were somewhat similar to the precedents established in literature. "*Code and Overall environmental choice*" was ranked as the most important factor by the respondents for the adoption of the RwHTS by the (+RwHTS+BIM) and (+RwHTS-BIM). This result builds on and supports the work of previous researchers.

6.2.5 Contributions and Benefits

This section identifies contributions made to the existing body of literature, as follows:

- The study identified factors from the perspective of design firms that contributed toward the adoption of RwHTS.
- The study associated the factors that affect the adoption of RwHTS with the attributes of innovations, based on the inputs received from the respondents (design firm).
- The study further identified factors which were perceived as critical with the adoption of RwHTS for both BIM users and non-BIM users, based on the inputs received from the respondents (design firm).

One of the biggest benefits of the study was that it identified factors that contributed toward the adoption of RwHTS. These 26 factors can be used by designers who are adopting the identified RwHTS for the first time. Furthermore, this study also identified factors perceived to be critical by the two categories of the respondents. This study also identified the attributes of innovation which were perceived as important by the respondent of the two categories. It was observed that (+RwHTS+BIM) were able to associate more factors with Relative Advantage and Trialability than (RwHTS-BIM). These observations also indicate that BIM not only allows the users with higher visualization of the innovations but also realize the benefits of innovation and allow the potential adopters to try on a virtual world.

6.2.6 Future research

This section identifies the areas which need further research, or avenues of research that were opened because of this research.

The study indicated that other attributes of innovation for both categories of adopters (+RwHTS+BIM) and (+RwHTS-BIM) are associated with factors which are perceived to be more important than observability. Based on the data derived from the sorts, it can be concluded that observability does not play as important a role in the adoption of the selected RwHTS as other attributes of innovation do. An important expansion of this study would be to replicate the study on different stakeholders of the industry and observe the difference. As per Lee et al. (2003), we need to conduct more studies that analyze the importance of attributes of innovations with regard to general sustainable innovations. This identification would help product manufacturers and suppliers better orient their products to promote more widespread and effective adoption.

The participants for the second phase were selected on the basis of criterion sampling. These criteria were identified at the beginning of the study. However, a similar study could be replicated, but with randomly selected cases, to further validate the findings of this study and evaluate generalizability of the findings.

6.3 How do designers use Building Information Modeling (BIM) to enhance the acceptance of RwHTS? As per literature, BIM enhances visualization and visualization has been linked with observability, so does the use of BIM result in frequent adoption of RwHTS?

6.3.1 Introduction

This research question contains two separate elements, as the outcome for both was derived from the same research methodology. The second part of the question built upon the first part. The first part of the research question aimed at evaluating the use of BIM by the respondents to further enhance the adoption of RwHTS. BIM was defined as "*a digital three dimensional model linked to a database of project Information, and it can combine all the information from the design inception to the facility management*" (AIA 2007). BIM in literature has numerous aspects associated with it which can be broadly associated with its use as both a product and process (Jerignan 2007). The study aimed to evaluate whether and how designers used BIM both as product and process to enhance the acceptance of RwHTS. Further, the second part of the question then sought to determine whether use of resulted in the frequent adoption of RwHTS.

6.3.2 Point of departure

In order to identify the use of BIM both as product and process to enhance the acceptance of RwHTS by designers, it was critical that the general design process followed by designers for the design of green buildings that utilize RwHTS be understood. Once general design process followed by designers was identified, then the identified design process could act as a baseline to gauge how BIM changes the identified design process so as to enhance the adoption of RwHTS. Although there are multiple guidebooks/models for the design process, the study revealed that the architectural firms are prone are prone to external variables and constraints such as varying codes, budget, project requirements, stakeholder expertise, varying expectations of stakeholders, degree of collaboration and other factors. These factors suggest a need for a descriptive study of the design process followed by design firms, which was a primary aim of this research. There was also a lack of understanding of how this design process was altered by the use of BIM. The adoption of BIM by architectural firms in itself adds a new paradigm to design process, as per the researchers (Arayici et al. 2011; Jernigan 2007). In addition, researchers have asserted that in order to improve a process, one must first understand the actual design process for green buildings (Horman et al. 2006) so as to enable a deeper understanding of potential improvement impacts (Reed and Gordon 2005). Others have also stated that the design process is highly dependent on the project type and factors associated with the project such as stakeholders, site, climate, uncertainties etc. (Magnet 2005). The current literature on green building shows that the design process for green buildings with regard to the AEC industry is largely undefined. Therefore, there was a need to conduct a descriptive study that characterizes the design process for green buildings followed by designers for private projects, and then this identified process could act as a baseline to understand how designers use BIM to enhance the acceptance of RwHTS and investigate whether the use of BIM results in frequent adoption of RwHTS. In addition it, there is evidence from literature that was that BIM enhances visualization (Campbell 2007; Staub and Khanzode 2007; Glick and Guggemos 2009; Korkmaz et al. 2010), and visualization has been linked to observability by researchers, which is one of multiple attributes of innovation. Literature in the domain of adoption and diffusion of innovations states that attributes of an innovation, which include observability, are critical to the diffusion and adoption of that innovation (Askarany et al. 2007; Atun and Sheridan 2007; Black et al. 2001; Rogers 2003; Habets et al. 2006; Scott et al. 2008; McCoy 2008; McCoy et al. 2012). Hence, it became imperative to evaluate whether the use of BIM by designers results in frequent adoption of RwHTS. Thus, these two questions provided a unique opportunity to observe how designers across the southeastern coast of the U.S. utilized BIM and further understand the thoughts of the designers about the influence of BIM on the design process.

6.3.3 Validity

The third research question involved qualitative research method, using the holistic case study method. This method has been explained in Chapters 2 and 5 and was utilized to characterize the design process followed for green buildings where RwHTS were adopted. In addition the research further tried to understand how designers use BIM to enhance the acceptance of RwHTS. The participants for this phase were shortlisted from the set of respondents who were a part of the phase I. The first phase involved survey methodology, as explained in Chapter 2 and 3 primarily to observe the implementation patterns for RwHTS and BIM. Furthermore, interviews as a part of the holistic multiple case study were used to determine whether the implementation of BIM contributed to the frequent adoption of RwHTS. In order to determine the validity of the whole process, credibility, dependability, transferability, and confirmability were used as validation strategies (Trochim 2006).

6.3.3aCredibility

As indicated in the previous section, the participants in the multiple case studies were selected on the basis of responses provided to the survey. The researcher did not have any previous working relationship with any of these subjects, thus avoiding any personal bias. Furthermore, as indicated in chapter 5, all the information that was collected was validated by the respondents prior to analysis using a process of member checking. Data were collected by multiple methods including video recording, process maps, and manually noting the responses. In addition, all the responses were overlapped and the generalized cases represented. Last but not the least, all the information was collected by utilizing redundant methods as mentioned in chapter 5, so as to avoid any error while transcribing the information.

6.3.3b Transferability

The research intended to determine whether the use of BIM enhanced the acceptance of RwHTS by designers, and further evaluate whether the adoption of BIM resulted in frequent adoption of RwHTS. For this purpose as mentioned above, the holistic case study yielded the results for this study. This method has been actively used in the realms of social science and the established framework by Yin (2009) was adapted to compliment the research question. The adapted method was pilot tested to enhance validation. The recommendations of the pilot test were incorporated to strengthen the case study protocol, which has been discussed in Chapters 2 and 5.

6.3.3c Dependability

Multiple case studies with a holistic design approach were used to address the research question in the second phase of the investigation. The objective of understanding the design process adopted by the design firms was one of the major reasons for adopting this approach. Multiple cases for each category (+RwHTS+BIM) and (+RwHTS-BIM) used exact replication of the research design. Protocols for the case studies were established early in the second stage of the research, which then acted as the guiding document for the rest of the case study.

6.3.3. d Confirmability

With regard to the adoption of BIM, certain adopters of BIM indicated its use as a tool/product to achieve better visualization, creating better presentations, achieving better coordination amongst stakeholders than as effective process tool. These results suggest that designers in general may be still coping with limited use of BIM as a decision tool, due to numerous factors mentioned in Chapter 5. Furthermore, even the firms which appeared to be pioneers in adoption of BIM in this research were still learning to cope with the use of BIM due to numerous limitations such as interoperability issues, costs, learning curve, effect of stakeholder participation, owner awareness, and others.

6.3.4 Conclusions and limitations of the research

The overall conclusion of the study, supported by interviews with designers, was that BIM adoption does not at this time lead to frequent adoption of RwHTS due to multiple reasons, such as the way BIM is used, the limitation present in the BIM and RwHTS software, and others Section 6.4 discusses the path for the integration of the two concepts. Additionally, general design process adopted by designers for the design of green buildings employing RwHTS was the outcome of this stage of the research. Many commonalities were identified across the case studies and have been discussed in the previous chapter. The study also found that the design process followed by (+RwHTS+BIM) was not majorly different from (+RwHTS-BIM). Hence, with the way BIM has been used currently by responding design firms, no significant change in the design of green buildings was observed with the use of BIM. This finding can be attributed to partial adoption of BIM, which was observed in the results of the Phase I survey and supported by the case studies. Certain respondents, even in the case study, indicated that they used BIM only as a product and still trying to use it as a process. The study revealed that adopters of BIM focused on higher visualization, creating presentations, and coordination amongst stakeholders as their primary uses of BIM as a tool. Other benefits of BIM were not commonly utilized by some case study firms, as they incur an additional cost and time investment for the adopting unit. Thus certain design firms studied are still coping with the use of BIM as a decision and parametric tool, due to numerous factors such as direct and indirect cost, liability, interoperability, risk, proficiency, and others. The major difference identified was the fact that BIM adoption had reduced the rigidity and formalization in the design process, and enhanced visualization and communication. This was difference was also observed within the (+RwHTS+BIM) category. Firms using BIM both as product and process were observing the abovementioned results to a certain degree.

The study concluded that BIM did not result in frequent adoption of RwHTS. However, at the same time, there was an indication that adopters of BIM and RwHTS might be adopting these innovations because of the inherent nature of the firm. In other words, this very inherent nature of the firms was causing the adoption rather than (or as much as) the specifics of the innovation itself. This idea emerged as an area for further investigation in future research.

In addition to above, time expected to be spent by the designer to participate may have been an issue as observed for this study. In terms of achieving convergence for developing a universal design process for green buildings, other methods such as the Delphi method may have been more suitable from a convergence standpoint although more challenging from a logistical standpoint.

6.3.5 Contributions and Benefits

This section identifies contributions made to the existing body of literature from this phase, as follows:

- The study identified the design process followed by designers to design a green building and generated a common process that was representative of the processes described by the case study participants.
- The study investigated the differences in design process for a green building where RwHTS was adopted, between the categories of (+RwHTS+BIM) and (+RwHTS-BIM).
- The study further investigated whether the adoption of BIM caused the adoption of RwHTS and found moderate relationships between the two in survey results that was discounted by the participants in the case studies.
- The study compared the adoption of BIM and RwHTS. It found that the adoption of BIM was less common than the adoption of RwHTS by firms reporting adoption on at least one project. One factor that could explain this difference is that BIM is a relatively newer concept than RwHTS. Accordingly diffusion has had less time to occur, leading to the conclusion that the two concepts are independent.
- As per the responses to the survey, the study also found that the adopters of BIM who adopted all the functions were much less than adopters of RwHTS who adopted all the types. One of the reasons which can be attributed to such a difference can be the time of inception of the innovation.

One of the biggest benefits for the designers was that a generalized design process for the design of a green building was developed, which is representative of the trends followed by case study firms. As a result, champions of BIM can evaluate where BIM is falling short in adoption and diffusion by design firms. Hence, based on the adoption patterns of BIM among designers these champions now have the potential to align their strategy to improve the market penetration in a shorter span of time. The study also provides an insight for design firms that the potential of BIM is way beyond that of a visualization, presentation, and collaboration tool. In order to achieve maximum benefit, use of BIM as a product and process is necessary.

6.3.6 Future research

Multiple similarities were observed between the concept of BIM and RwHTS, and RwHTS is a subset of sustainable innovations. A potential future research would be to identify whether the similarities identified overlap sustainable innovations. In addition, it would be interesting to observe if BIM adoption is following the similar trends that sustainability has gone through in the last four decades. If so, numerous parallels can be drawn and mistakes avoided in enhancing the adoption of the BIM. The study also found that very few respondents were holistically (as product and process, and within product all the identified/applicable functions) adopting the concept of BIM within their organizations. Even though studies in literature have stressed the need for adoption of BIM as a product and process for potential adopters the results of this study show that design firms have not yet achieved this goal. Another future study can observe how those respondents who were adopting BIM on a limited basis were coping with the reduced efficiency. Was reduced throughput making design and construction firms identify and accept their fallacy and making them take a corrective recourse, or are those industries still not realizing that they are working on a reduced throughput? In addition, it would also be important to recognize the factors that lead to the adoption of BIM on a limited basis, and then compare them with the factors identified in literature such as cost, time to input additional information, and liability of the model.

Many respondents also reported that the decision to adopt RwHTS was simple and they did not require complex analysis tools to decide on adoption, as opposed to the adoption of energy or day-lighting strategies. Also as per the respondents, the market does not presently offer software for RwHTS simulations that takes into account the complex changes in weather patterns that have been recently observed, meaning that simple tools presently available do not offer the ability to accurately predict system behavior. McGraw-Hill (2010) conducted an analysis on the adoption of Green BIM and identified the need of intelligent water simulation tools. Hence, decision tools for RwHTS available need to be analyzed to ascertain if the problem exists. Also investigations should be conducted to identify how connected the existing software tools are with the weather models. The importance of weather models is highlighted by the fact that they are required to provide more accurate performance forecasting, considering the requirements for RwHTS such as first flush, containment size, rain frequency, and others that can contribute towards the success/failure of RwHTS.

Furthermore, it was also realized that although that industry is moving towards better integration, at the same time there are still many fragments where some stakeholders lie and they do not encourage the interdisciplinary approach adopted by the industry. The effect of these stakeholders operating on these fragments needs to be analyzed with respect to the designers.

Various contractual methods also have the potential to change the general design process developed for a green building which adopts RwHTS; the design process generated could vary as new contractual methods are introduced. Future studies should take into account the variation in design resulting from differences across contractual methods.

6.4 Commentary

The study identified that as per the current adoption patterns observed within the design industry for BIM and RwHTS, it is difficult to integrate the two. Integration of the two is perceived as not feasible for designers, at this point of time, due to multiple reasons. The subsequent section discusses the challenges the designers faced integrating the two.

6.4.1 Absence of interoperable decision tool

BIM has been cited to reduce complexity of an innovation. For +RwHTS+BIM, the benefits of BIM adoption were perceived greater when the decision tools for innovation adoption were interoperable with the tools used by the designers. However, for the adoption of RwHTS, the respondents mentioned the use of excel or customized decision tools. Such tools were perceived to be context specific and non-interoperable with the design tools used by the adopters of BIM. Thus, most of the information needed to be duplicated and other benefits of BIM, such as enhanced visualization, trialability on virtual domain, analyzing relative advantage, and others were reduced considerably. The major advantage that adopters of BIM had was in terms of partial visualizations and trialability. However, prior to the creation of a decision tool interoperable with the tools used by the designers, the decision tool needs to be robust, dynamic, and able to guide the users in the adoption of RwHTS. The subsequent section discusses the development of such a decision tool.

6.4.1a Identification and design of robust and dynamic interoperable decision tool

Firstly, an inventory of existing decision tools needs to conducted to analyze the strengths and weaknesses of the available tools. Certain parameters, such as interoperability of software with existing tools used by designers, ability of the decision tool to conduct analyses, accounting for micro-climate, and others need to be set for such an evaluation. In addition, analyses of codes need to be conducted to realize the geographic locations and building types within those particular geographic locations, where adoption of RwHTS is not permissible. Furthermore, weather models need to be assessed to ascertain if they are accounting for micro-climate within each region and the complex/unpredictable weather patterns observed lately. After doing so, if none is found, a decision tool needs to be designed. The proposed decision tool(s) need to possess the ability to account for complex weather patterns and micro-climate within regions, which involves building from the historical data on a micro level up to a macro (national) level. In addition, of the many RwHTS available, RwHTS can be implemented on a project, depending on the project requirements. The recommended decision tool can possess the capabilities to conduct various analyses such as life cycle cost, embodied energy, return on investment, and others so as to enable the owner/owner representative decide upon the feasibility. Interoperability of the decision tool with the existing tools used by designers is also important as this would reduce the load of redundancy of data input and enhance the accuracy of the previously mentioned analyses. In addition, the decision tool can be integrated with the local municipal information database pertaining to various geographical locations so as to analyze the code requirements and provide a feasible output to the design team. Furthermore, the type of building can affect the adoption of RwHTS, as has been observed in the preceding chapters. The integration of such information can be built as variable within the decision tool which freezes the types of RwHTS which cannot be adopted with certain building types for a geographic location. Lastly, the decision tool needs to be dynamic enough to account for all the various physical components associated with the RwHTS and then recommend to the design team the most optimal ones based on the factors cited as important. All this information should be supported by a knowledge base and the absence of knowledge base is an important issue which needs to be resolved. The next section discusses how creation of knowledge base is important for the integration of RwHTS and BIM.

6.4.2 Absence of knowledge base supporting the decision tool

Knowledge is cited as one of the factors that affects the adoption of innovation. Not only is it important to know about the innovation, in this case the RwHTS, but also, it is important to identify the optimal RwHTS for a certain project within a certain geographic location. The absence of a single comprehensive knowledge base supporting the decision tool is also an important factor which needs to be realized, prior to the integration or RwHTS decision tool with the BIM. BIM tools generally possess the ability to carry a wealth of information and so should the proposed interoperable decision tool. Furthermore, the knowledge base within the decision tool will reduce the complexity associated with the adoption of RwHTS. Complexity in literature has been cited to be inversely proportional with the adoption of an innovation. Hence, the more the complexity of the RwHTS is reduced, the more likely will be the adoption. But first a single comprehensive knowledge base needs to be created which is accurate, precise, and dynamic. A robust knowledge base should at least cover the following areas pertaining to the RwHTS:

- Identify the municipal codes for most/all regions and locating areas where RwHTS are prohibited.
- Identify areas where incentives are provided for the adoption of RwHTS which can then be built with life cycle cost analysis and feasibility analysis.
- Identify the various types of RwHTS and have the ability to conduct a dynamic analysis between one another based on the project size, location, site climatic/environmental conditions, and other important factors identified in the study.
- Associate a generalized cost calculation with each type of RwHTS.
- Compile detailed rainfall and weather patterns for microclimates within each region throughout the country. The weather patterns should not be completely based on historical data, but should also consider the complex weather patterns observed lately.
- Create detailed owners operation guide manuals for each of the RwHTS.
- Create and compile comprehensive rating systems for the operations and maintenance (O&M) of each RwHTS, since O&M was cited as a major barrier for the adoption of RwHTS.

Even after the creation of a robust, dynamic, and interoperable decision tool supported by a knowledge base, the chances of its success are not complete since it is the designers who use the tool, and improper adoption of tools can cause frustration. This can further result in the discontinuation of the tool. It has been observed that there is a propensity among the adopters to use BIM as a product instead of fully integrated into design as a process. To prevent similar problems for the adoption of the decision tool, the use of BIM as an analysis and evaluation tool needs to be stressed. The next section discusses this in detail.

6.4.3 Actively utilizing the most functions of BIM for the decision tool

The survey response depicted that not all functions of BIM were uniformly adopted among the designers. Certain functions, such as visualization and initial presentations, were used more often than the others. The adopters need to utilize more frequently other functions of BIM, which involve the use of BIM as an analysis and evaluation tool as well as a communication and collaboration tool. When use patterns shift for a majority of users, the linking of a RwHTS decision tool to BIM would become feasible. Integration between BIM and RwHTS can be achieved by designing plugin(s) between the RwHTS decision tools and BIM tools used by the designers. This also means that the decision tool used to decide upon adoption of RwHTS does not need to be interoperable with the object oriented modeling software of one company. Hence, this offers designers the flexibility to use the tools which they perceive to be optimal and meet their requirements.

In addition, while designers will be using such tools, it is of the utmost importance that the users be trained for the proper use of BIM and the decision tools. Training reduces the perceived complexity associated with the decision tool, promotes proper usage, and sets realistic expectations from the tools. As seen in the study, certain adopters were frustrated with BIM as they believed BIM failed to deliver complete benefits. The adopting units must train their staff with the adopted tools and work processes. This enables generation of realistic expectations from the adoption of BIM and the proposed decision tool. Training of employees, incorporation of appropriate interoperable software, and change of work processes will in most cases incur direct and indirect costs and reduce productivity in the initial phases of the adoption to the adopting unit. The adopting unit must be willing to incur these costs. In addition, setting realistic expectations and identifying the limitations of the software to be adopted must be incorporated from the very beginning of the adoption, and all members of the adopting unit made aware of it.

Thus, to sum it up, in order to integrate RwHTS, the designers not only need a robust, dynamic, and interoperable RwHTS decision tool, but also a comprehensive knowledge base to support it. They also need to start to actively utilizing more functions of BIM for the decision tool, if they not already done so. Apart from the features of the software product, changes need to be incorporated in the *usage* of the products. Hence, a two pronged approach, involving the decision tool design with supporting infrastructure and changing adopter usage patterns, needs to be incorporated, prior to the integration of RwHTS and BIM.

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Appendices

This section represents the appendices used for the research. Appendix A represents the questions asked in the survey which was conducted in the Phase I of the research. Appendix B and C represents sent to the representatives from (+RwHTS-BIM) and (+RwHTS+BIM) category.

Appendix A

Q1) Your name? ____________________

Q2) Your job title?___________________

Q3) Your contact information

Telephone (Office with extension) [ ]

Telephone (Mobile) [ ]

Email [ ]

Q4) Tell us about the organization you work for

Name of Organization [ ]

City in which your organization is located [ ]

State in which your organization is located [ ]

Q5) Select the state(s) in which your organization has offices (Select all that may apply):

- [ ] Florida
- [ ] North Carolina
- [ ] Maryland
- [ ] Georgia
- [ ] Virginia
- [ ] District of Columbia

- South Carolina

Q6) Number of employees

- < 10
- 11-25
- 26-50
- 51-100
- 101-500
- > 500

Q7) How long has your organization been in business?

- < 1 year
- 1 - 5 years
- 6 - 10 years
- 11 - 25 years
- 26 - 50 years
- > 50 years

Q8) Has your organization designed any federal project between 2000-2010?

Yes

No

Q9) What type(s) of projects has your organization undertaken between 2000-2010? (Select all that apply)

- Commercial
- Financial
- Fire Station
- Industrial
- Health Care
- Hotels
- Housing
- Library
- Mixed-use
- Municipal
- Museum
- Office
- Performing arts
- Religious
- Restaurants
- Schools
- Storage
- Universities
- Other

Q10) Has your organization designed a Green building(s) between 2000-2010? (Click on the term for the definition)

Yes ● No ●

Q11) Which of the following rain water harvesting systems did your company use on projects between 2000-2010? (Select all that may apply and click on the term for their definitions)

- ☐ Above-ground rainwater storage
- ☐ Bioswale
- ☐ Constructed wetland
- ☐ Extensive green roof
- ☐ Intensive green roof
- ☐ Permeable pathway
- ☐ Rain garden
- ☐ Retention pond
- ☐ Under-ground rainwater storage
- ☐ None
- ☐ Other ______

Q12) Name some Green building(s) that your company designed between 2000-2010?

Q13) Has your organization used Building information modeling (BIM) on any project between 2000 - 2010? (Click on the term for the definition)

Yes ● No ●

Q14) Specify the areas for which you use Building information modeling (BIM) (Select all that apply and click on the term for the definition)

☐ Clash detection	☐ Initial presentations	☐ Restoration and renovation
☐ Constructability	☐ Interior environmental analysis	☐ Sustainable design
☐ Construction drawing (e.g. for prefabrication or contractor)	☐ LEED	☐ Value engineering
☐ Database information management	☐ Municipal code compliance	☐ Visualization
☐ Design of complex structures	☐ Parametric design	☐ None
☐ Estimation	☐ Performance optimization (e.g. shading systems)	☐ Other ______
☐ Facility management	☐ Site analysis	

Q15) Name some projects that your company designed while using BIM between 2000-2010?

Q16) Has your organization used Building information modeling (BIM) for any of the Green building(s) designed between 2000-2010? (Click on the term for the definition)

Yes	No
●	●

Q17) Has Building information modeling (BIM) been used for any non-federal or non-state agency owned Green building(s), designed by your organization between 2000-2010?

Yes	No
●	●

Q18) Name some green building that your company designed while using BIM between 2000-2010?

Q19) Drag the project types in the left column into respective groups in the order they are most designed by your organization. If there are any project types that your organization does not design, please leave that type in its own place.

(e.g. If your organization mostly designs green commercial projects followed by green fire stations, then place the commercial and fire station into the box designated as "Designed using Green Technologies", with commercial as number1 and fire station as number 2. The order in the box should reflect the usage of green projects)

Items	
Commercial	
Financial	Designed using green technologies and BIM
Fire Station	
Hospitals	Designed using BIM
Hotels	Designed using green technologies
Housing	
Library	
Mixed-use	Designed using none
Municipal	

Museum

Office

Performing arts

Religious

Restaurants

Schools

Storage

Universities

Other

Q20) Would you like to receive information about the results of this study?

Yes	No
●	●

Appendix B

These questions were sent to the representatives from (+RwHTS-BIM) category.

The Rainwater Harvesting Technologies and Strategies (RwHTS) analyzed in this study include green roofs (intensive or/and extensive), rain water storage tanks (above or/and below ground), and permeable pathways.

<table>
<tr><th>Step I in the discourse</th><th>Step II in the discourse</th><th>Step III in the discourse</th></tr>
<tr><td>Generally how is a facility designed?
This question will address the following areas for projects in general:
• Stakeholders involved and their roles and responsibilities at each stage
• Identify the process from initial proposal to 100% CD
• Information exchange (protocols if any followed)
• Data storage/ archival/ documentation/ other information
• Software, if used at each stage
• Major and interim stages for design
• Detailed hierarchy of work responsibilities at each stage
(Output: Process map)</td><td>Factors that cause the incorporation of RwHTS (Cost, municipal codes, aesthetics, others)
(Output: Obtain a list of factors)</td><td>Generally how is/are RwHTS implemented?
This question will address the following areas for projects in general:
• The detailed delivery process from recommendation of RwHTS to implementation
• Generally, who is responsible for providing recommendations?
• Stages involved in the process of implementation
• Point on the process map created in step I, where recommendations and implementation of RwHTS would generally occur</td></tr>
<tr><td></td><td>For what percentage of the projects do you recommend RwHTS?
(Output: Distribution of individual responses)</td><td>After initial implementation of RwHTS in a design, can it be rejected at a later stage of any project? What are the probable factors responsible for its rejection?
(Output: Obtain a list of factors that cause rejection after initial implementation)</td></tr>
</table>

Appendix C

These questions were sent to the representatives from (+RwHTS+BIM) category.

The Rainwater Harvesting Technologies and Strategies (RwHTS) analyzed in this study include green roofs (intensive or/and extensive), rain water storage tanks (above or/and below ground), and permeable pathways.

Step I in the discourse	**Step II in the discourse**	**Step III in the discourse**
Generally how is a facility designed? This question will address the following areas for projects in general: • Stakeholders involved and their roles and responsibilities at each stage • Identify the process from initial proposal to 100% CD • Information exchange (protocols if any followed) • Data storage/ archival/ documentation/ other information • Software, if used at each stage • Major and interim stages for design • Detailed hierarchy of work responsibilities at each stage *(Output: Process map)*	Factors that cause the incorporation of RwHTS (Cost, municipal codes, aesthetics, others) *(Output: Obtain a list of factors)*	Generally how is/are RwHTS implemented? • The detailed delivery process from recommendation of RwHTS to implementation • Generally, who is responsible for providing recommendations? • Stages involved in the process of implementation • Point on the process map created in step I, where recommendations and implementation of RwHTS would generally occur
In general, at what point on the process map do you start using BIM and where does it end? *(Output: Identify the areas on the process map created)*	For what percentage of the projects do you recommend RwHTS? *(Output: Distribution of individual responses)*	After initial implementation of RwHTS in a design, can it be rejected at a later stage of any project? What are the factors responsible for its rejection? *(Output: Obtain a list of factors that cause rejection after initial* implementation*)*
Locate the areas on the process map that you think have changed due to the use of BIM in comparison to earlier projects when BIM was not implemented. *(Output: Identify areas that changed with the use of BIM)*		Do you think BIM has been successfully used to overcome the negative factors of RwHTS? If yes, then how? *(Output: List of barriers for implementation of RwHTS and how BIM resolved the barriers)*