EVALUATING INNOVATIVE TECHNOLOGIES IN CONSTRUCTION INDUSTRY: THE CASE OF HIGH RISE BUILDINGS

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ABSTRACT

Construction industry is associated with risks and uncertainties, due to its nature. On the other hand, those risks and uncertainties have instigated the discovery of innovative technologies to eliminate risks and uncertainties. Although technologies in construction industry is being innovated to provide solutions for potential issues on time, cost, quality, and sustainability, past researches still emphasis that the construction industry is not yet developed as other parallel industries. In the post war period, Sri Lankan construction industry became vast and advance with high rise building constructions. Land scarcity and high population growth are reasons for such tremendous development of high-rise buildings. However, the deficiency in the development of technologies in the construction industry does not fulfil modern necessities.

Therefore, the purpose of this research paper is to investigate the innovative technologies adopted in high rise building construction projects in Sri Lanka, for a successful completion within the budget, on time, and with adequate quality. A comprehensive literature review survey was performed to identify innovative technologies integrated in building construction industry during the design and construction development phases. Data were collected through eight (08) ongoing high rise building projects located in urban Colombo area, and these data were categorized according to the cases and presented as percentages among the projects. The results from the study revealed that the use of innovative technologies vary, and currently, common technologies are used during the design and construction phases. Further, the study identified identical benefits the client and the contractor can gain by using innovative technologies, and the challenges faced by industry stakeholders.

Keywords: *Benefits; Challenges; High-rise buildings; Innovative technologies.*

1. INTRODUCTION

Construction is defined as the combination of physical infrastructure, civil-engineering work, all building work, and the maintenance and renovation of existing structures (Wells, 1985). However, because of its nature, the construction industry is associated with risks and uncertainties. According to Dubois and Gadde (2002), uncertainty in construction happens due to four major reasons: (1) management is unfamiliar with local resources and the local environment; (2) lack of complete specifications for construction activities; (3) lack of uniformity of projects; and (4) unpredictability of the environment. Nguyen and Chileshe (2015) stated that outdated technologies are a major reason for a project failure, while Assaf and Al-Hejji (2006) implied that lack of innovative technology implementation cause project to delay. This bears evidence that the construction industry require innovative technologies for managing risks and uncertainties. Consequently, Rosenberg (2004) said that “Uncertainty” is the single feature that dominates the search for innovative technologies and innovation must have been a major force in the growth of output in highly industrialized economies.

As per Kavilkar and Patil (2014), innovative technologies support the construction of safer and economical buildings. According to Warszawski and Navon (1998), the main aspects of innovative technologies are maximizing production, minimizing labour resource, and improving quality. Rosenberg (2004) argued that the mechanized manufacturing methods reduce labour cost up to 30%, and Bock (1998) stated that using

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innovative technologies can save time, cost, and quality of the product. In the same way, Kyjakova, *et al.* (2014) reported that innovative technologies permit the construction of attractive buildings of any size, preferably with several storeys, and custom designed to meet specific requirements. Egan (1998) and Benmansour and Hogg (2002) explored the benefits due to innovation in the construction as improved living and working conditions, lower costs, sustainability, high profitability, and a lesser impact on the consumption of energy and environment. While the Sri Lankan construction industry is in boom through the past decade, innovative technologies entered in to Sri Lankan industry more than ever in the post-conflict scenario in the country, after the end of the ethnic war in 2009. With the revolution of the construction industry, more of high rise building projects started than in the past, especially in Colombo and suburban areas. Therefore, the purpose of this paper is to investigate the innovative technologies adopted in high rise building construction projects in Sri Lanka. Various authors used different terminologies for innovative technologies such as modern technologies (Väha *et al*., 2013), advanced technologies (Kildienė, *et al.*, 2014) and new technologies (Hing, 2006), but the term 'innovative technology' was adopted throughout this research study.

The paper structure begins with an introduction to the study, followed by a literature review on necessity of innovative technologies in high rise building construction industry, drivers, benefits, and challenges. The research methodology, data collection, and data analysis are presented next, and finally, the paper presents conclusions derived from research findings with recommendations.

2. LITERATURE REVIEW

2.1. INNOVATIVE TECHNOLOGIES IN CONSTRUCTION INDUSTRY

The definition given for innovation by Slaughter (1998) is, "the actual use of a nontrivial change and improvement in a process, product, or system that is novel to the institution developing the change." According to Ling (2003), innovation is "a new idea that is implemented in a construction project with the intention of deriving additional benefits, although there might have been associated risks and uncertainties." Moreover, it is pertinent to note current industrial practices deviating from the conventional path of innovative technologies. Puddicombe (1997) highlighted that in response to the increasing complexity of modern construction projects, industry practitioners have differentiated themselves. "Already there have been many efforts to apply the evolving computer science software technologies loosely called 'artificial intelligence' to construction" (Bock, 1998). Furthermore, Sakamota and Mitsuoka (1994) stated that new machines need to be developed for better usage and improvement of the productivity in building construction. Moreover, Sakamota and Mitsuoka (1994) explored the mechanized construction system, which is carried out by machines, by considering the introduction of technologies and ideas from construction to other sectors such as mechanical engineering, electrical engineering, electronic engineering, and Information Technology (IT) sections.

Hu (2016) argued that the people's demand for construction development is the pathway for the technological innovation of construction that can support the builders to achieve their goals. According to Hu (2016), innovative technologies can ensure the aspects of a construction project and builders can improve safety during construction. Furthermore, the same author mentioned that innovative technologies and techniques are strategies to save resources and implement environmental-friendly constructions. Then the development of projects and sustainable development of human society become major aspects of innovative technologies. The author further argued that saving time, shorter construction period, saving labour costs, and improved quality, are the general aspects of innovative technologies, whereas ultimate output of innovative technologies is improving the living conditions of people in the society. Kildienė *et al.* (2014) stated that construction innovation is more effective than conventional methods and some are novel solutions for problems confronted in conventional methods.

Kildiene *et al*. (2014) explained that the improvement of the quality of human behaviour, distribution of technologies, reducing cost and time, and sustainability, are the aims of the construction sector. A key feature to achieve such aims is the use of innovative construction materials and technologies. Figure 1 illustrates the concept of development of the advance technologies. According to Kildiene *et al*. (2014), innovative technologies in the construction industry fulfil the major concern on cost, time, and sustainability, which are developed and tested as a prototype model in the laboratory and environment to provide the optimum output (refer Figure 1).

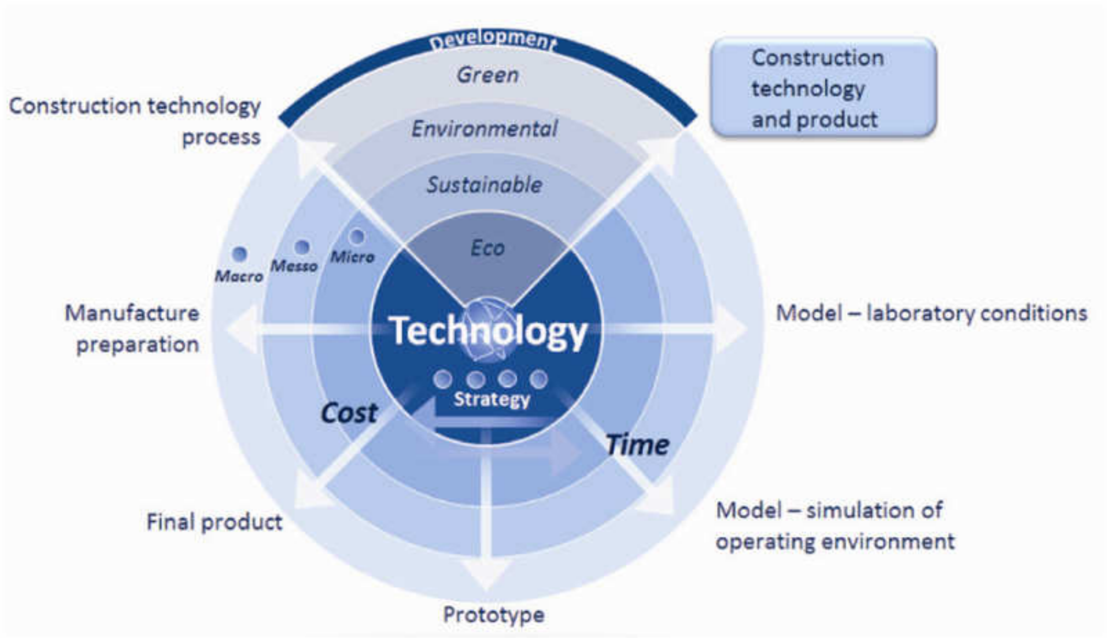

Figure 1: Advance Technology Development Concept

(Source: Kildienė *et al.*, 2014)

2.2. INNOVATIVE TECHNOLOGIES IN HIGH RISE BUILDING CONSTRUCTION

Thapa, *et al*. (2013) identified that massive population and land scarcity increase the demand for high rise buildings. The authors argued that innovative technologies are major factors for the success of high rise building construction. The technological development, population density, good financial power, and reputational competition, increase the demand for high rise building construction. Many authors have discussed innovative technologies which can adopt during the design phase, substructure construction phase, and superstructure construction phase. Dossick and Simonen (2014) introduced BIM as a solution to a potential problem in high rise building design due to scope, complexity, and constructability, and explained that potential conflicts can be solved by BIM before the construction. Alshanbar (2014) stated that BIM is an innovation tool in the design process in modern construction.

Sandelin and Budajev (2013) identified wind as a major problem in high rise building construction and explained various tubular systems in the current construction industry. Vähä, Heikkilä, and Kilpeläin (2013) identified automated operation in digital form for measuring work, levelling, and surveying, as an alternative for manual measurement tools tape measures, transits, levels, and plummets. Digital theodolites or tachometer (a combination of a theodolite and an electronic distance measuring device), GNSS (Global Navigation Satellite System), laser planes levels, and plummets, are used for positioning purposes.

Haowen (2015) specified that innovative formwork systems are the best solution for difficulties faced in high rise buildings, such as high position for work, low position for supporting, aerial movement of formwork, and sufficient strength. PERI formwork system (Loret *et al*., 2015), crane operated climbing formwork system (Dahlin and Yngvesson, 2014), andslipping formwork system (Loret *et al*., 2015), are some advance formarwork systems discussed in the literature. Iwiss (2008) introduced electric rebar cutter machines that can cut rebar easily and accurately. When the diameter of the reinforced bar increase, the lap length also increase. As a solution, Outakumpu (2013) introduced reinforced bar couplers that are more cost effective and save 52d length in each bar. Väha *et al.* (2013) described about an innovative machine for plastering and explained on uniqueness. Table 1 presents some innovative technologies used in high rise building construction during design phase, substructure construction phase, and superstructure construction phase, identified through a critical literature review.

Table 1: Innovative Technologies in High Rise Building Construction during Design and Construction Phases

Building Phase	Innovative technologies	
Design Phase	**Building Information Modelling(BIM)** (McCuen and Tamera, 2014; Alshanbar, 2014)	
	Frame (Design developments in structure) (Sandlin and Budajev, 2013)	**Tubular systems** (Sandlin and Budajev, 2013)
	Dampers	Trussed tube system
	Shear wall	Bundled tube system
	Rigid frame	Tube in tube system
	Bracing	Core with outrigger system
	Braced rigid frame	Buttressed core system
		Tubed mega frame system
Construction Phase- Sub Structure	**Earthmoving works (intergraded with any other method) (***Pan and Hou, 2016)*	
	Measuring Tools (Digital or any)	**Pile Foundation (Väha *et al.*,2013)**
	Levelling Tools (Digital or any)	*Automated piling systems*
	Surveying Tools (GPS or any)	*PHC screw piles*
	Positioning Tools (GPS or any)	*Large diameter bored pile*
		H-pile
		Mini-pile foundation
		Intergraded with GPS
Construction phase-Super structure	**Formwork material**	***In situ* concrete**
	Aluminium formwork	*Self-compacting concrete*
	Fibber glass formwork (Richard,1962)	*Self-levelling and self- curing concrete*
	Plastic formwork	*Magnetically driven concrete*
	Advanced formwork systems	*Self-healing concrete* (Honkers, 2011)
	Crane-operated climbing formwork	*Alternative for Portland cement*
	*System formwork (PERI System) (*Loret *et al*., 2015)	**Light weight concrete**
	Slip formwork system (Loret *et al*., 2015)	**Carbon nanotubes**
	Hoisting and Working platform (Acuna, 2000)	**Pumping system**
	Gondola/Swinging Stage	*Truck-mixture concrete pumps*
	Work platforms	*Staged pumping*
	Automated building construction system (ABCS) (Miyakawa*et al*., 2000)	*Stationary concrete pumps and booms*
	Automated crane	**Prefabrication of elements** (Acuna, 2000)
	Reinforcement (Thillairaja, *et al*., 2015;Iwiss, 2008; Outakumpu, 2013)	*Pre-tension concrete element*
	Reinforced bar bending machine	*Post-tension concrete element*
	Rebar cutter (RC)	*Precast concrete*
	Portable rebar tying tools	**Contour crafting (layer fabrication)**
	Reinforced bar coupler in columns	**Sandwich panel**
	Cup lock Scaffolding (SGB-Group,2005)	
Finishes (Väha *et al*., 2013)	**Plastering machinery**	**Tiling machines**
	Painting machines	**Epoxy flooring**
		Power trowelling

2.3. *DRIVERS AND BARRIERS TO IMPLEMENT INNOVATIVE TECHNOLOGIES*

Ahn *et al*. (2013) identified some drivers to implement innovative technologies with sustainable construction as follows: Energy, environmental, and resource conservation, Regulations and policies, Reduction of waste, Proactive of product and materials, Cost transparency, Building rating methods (LEED, Green Globes), Educating and training facilities, Recognition of commercial buildings as assets, Proactive performance, Success of complicated high rise building design, New kinds of procurement methods, High productivity, Improving sustainability and quality, Awareness from clients, Improving social benefits, and cost reduction. Winch (2003) stated the productivity, quality, and value of money, were not developed with parallel industries due to lack of innovation in construction.

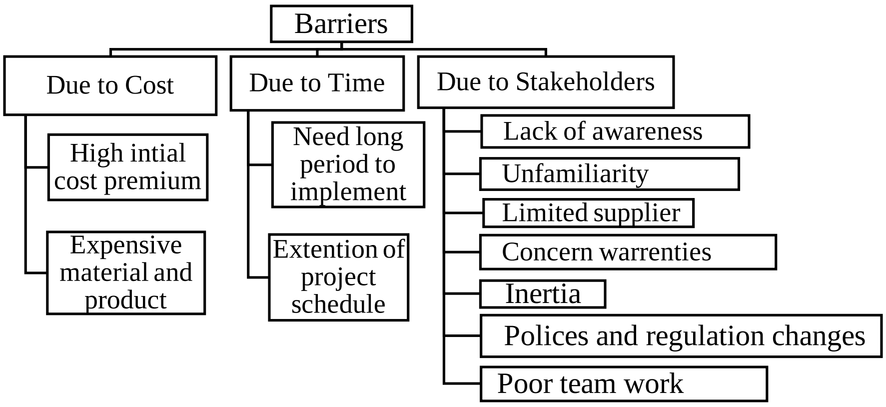

Figure 2: Barriers for Implementing Innovation Technologies

(Source: Ahn *et al*., 2013)

Benmansour and Hogg (2002) investigated barriers to adopt innovative technologies to a project due to deficiency of infrastructure, shortages in education and training, legislation problems, discouraged aspects of clients and engineers, and production of unique. Ahn *et al*. (2013) identified that barriers for innovation technologies depend on sustainable construction. Those barriers could divide into main three groups; barriers due to cost, barriers due to time, and barriers due to stakeholders. Figure 2 illustrates such barriers under each heading.

3. RESEARCH METHODOLOGY

This research paper aims to investigate the innovative technologies adopted in high rise building construction projects in Sri Lanka for a successful completion within the budget, on time, and with adequate quality. To fulfil the research aim, the study selected eight (08) ongoing high-rise buildings, with over twenty storeys (20) and located in Colombo area, to investigate the current innovative technologies adopted during design and construction phases. As stated by Denzin and Lincin (2005), qualitative researchers study things in their natural settings, attempting to make sense of, or interpret, phenomena in terms of the meanings people bring to them. Case analysis data were summarised using the frequency and percentage basis. Table 2 illustrates general information of the selected cases.

Table 2: Profile of the Case Analysis

Description	**Case 1**	**Case 2**	**Case 3**	**Case 4**	**Case 5**	**Case 6**	**Case 7**	**Case 8**
Type	Hotel Building	Office Building	Residential Building	Multi purposive commercial building	Multi purposive commercial building	Office building	Residential Building	Residential Building
Employer	Private	Government	Private	Private	Private	Government	Private	Government
Contractor	Local	JV	Foreign	JV	Foreign	JV	JV	Local
Condition	Ongoing	Ongoing	Ongoing	Ongoing	Ongoing	Ongoing	Ongoing	Ongoing

ICTAD grading	C1 contractor	C1 contractor	C1 contractor	C1 contractor	C1 contractor	C1 contractor	C1 contractor	C1 contractor
Contract price	Rs. 9.0 Billion	Rs. 8.0 Billion	Rs. 14.7 Billion	Rs. 92.5 Billion	Rs. 31 Billion	Rs. 7.4 Billion	Rs. 7.0 Billion	Rs. 5.7 Billion
Height	205m	140m	264m	156m	175m	74m	77m	70m
No. of towers in Building	1	1	2	3	2	1	1	1

4. DATA ANALYSIS AND FINDINGS

The study findings discussed the use of innovative technologies under main four phases; Design phase, Substructure phase, Superstructure phase, and Finishes phase. In each case, the relevant information was collected through project managers, site engineers, project architects, project quantity surveyors, and technical officers where necessary.

4.1. ANALYSIS OF INNOVATIVE TECHNOLOGIES ADOPTED IN DESIGN PHASE

The current practice of innovative technologies during the design phase was summarized in Tables 3 and 4, based on the professional response.

Table 3: Analysis of Innovative Technologies in Design Phase

Innovative Technology	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	%
BIM	X	X	√	√	√	X	X	X	37.5
Dampers	X	X	X	X	X	X	X	X	0.0
Shear wall	√	√	√	√	√	√	√	√	100.0
Rigid frame	√	√	√	√	√	√	√	√	100.0
Bracing	X	√	X	X	√	X	√	X	37.5
Braced rigid frame	X	X	X	√	X	X	X	X	12.5

According to Table 3, some technologies are not yet practised while some have become common to all cases. Dampers have not been adopted in these projects and the braced rigid frame is less practised. On the other hand, shear wall and rigid frame are used in all projects. It revealed that these are the most popular techniques to withstand wind load, and became a common technology to all cases. Table 3 depicts the bracing is used in three projects, and BIM is executed in Cases 3, 4, and 5. The BIM applications were used in the above cases; however, these cases have not obtained the concept of BIM fully. "Revit" application was executed in most cases, and the emerged fact is, consultancy organizations, if they are foreign organizations, executed BIM. The findings revealed that Case 5 practiced higher innovative technologies compared to other projects. The lowest practicing was reported from Cases 1 and 8.

Table 4: Analysis of Tubular System

Innovative Technology (Tubular Systems)	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	%
Frame tube system	X	X	X	X	√	X	X	X	12.5
Trussed tube system	X	X	X	X	X	X	X	X	0.0
Bundled tube system	X	X	X	√	X	X	X	X	12.5
Tube in tube system	X	X	X	√	X	X	X	X	12.5
Core with outrigger system	√	X	√	√	X	√	X	√	62.5
Buttressed core system	X	X	X	X	X	X	X	X	0.0
Tubed mega frame system	X	X	X	√	X	X	X	X	12.5

The literature search identified seven tabular systems used in building projects. Based on Table 4, core with outrigger system was the most popular tubular system, since the core is a major concern in high rise buildings. The core was used to fix the lifts and used as services ducts. Hence, tube becomes a core part of the high-rise building constructions. However, trussed tube system and buttressed core system were not practised in any selected projects. Among them, Case 4 practised higher amount of innovative techniques under tubular system, where three proposed building towers could be seen under Case 4.

4.2. *ANALYSIS OF INNOVATIVE TECHNOLOGIES ADOPTED IN SUBSTRUCTURE PHASE*

Table 5 illustrates innovative technologies used in substructure phase with their percentages. In substructure phase, the measuring tool and large board piles received the highest percentage of 100%. The innovative total station is an electronic theodolite integrated with electronic distance meter (EDM). The respondents in Cases 1, 2, and 3 said that these are more accurate and highly user friendly. Therefore, they tend to use it as a measuring tool in high rise building constructions. Moreover, respondents highlighted that small errors in levelling, measuring, surveying, or positioning in bottom, will be a dominant issue due to height. All respondents indicated that accuracy in equipment is of high concern in high rise building construction. Therefore, electronic levelling tools and surveying tools become the trend. GPS integrated system is used for positioning, and laser plummet facilitates measuring and positioning due to high accuracy. As Table 5 depicts, those receive higher percentages comparatively. Almost all projects uses the large diameter board piles. Only Case 1 used piling machines integrated with GPS, but none of the projects used automated piling systems, PHC screw piles, and mini piles, because those are intended for special requirements. In addition, Cases 1, 3, and 8 used earthmoving machines integrated with GPS system, although the earthmoving machines can be only indicated in the marked positions.

Table 5: Innovative Technologies Adopted in Substructure Phase

Innovative Technology	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	%
Earthmoving works (GPS)	√	X	√	X	X	X	X	√	37.5
Measuring Tools (Digital or any)	√	√	√	√	√	√	√	√	100.0
Leveling Tools (Digital or any)	√	√	√	X	√	√	√	√	87.5
Surveying Tools (GPS or any)	√	√	√	X	√	√	√	√	87.5
Positioning Tools (GPS or any)	√	√	√	√	X	√	√	√	87.5
Pile Foundations									
Integrated with GPS	√	X	X	X	X	X	X	X	12.5
Automated piling system	X	X	X	X	X	X	X	X	0.0
PHC screw piles	X	X	X	X	X	X	X	X	0.0
Large diameter bored pile	√	√	√	√	√	√	√	√	100.0
H-Pile	√	√	X	X	X	√	√	X	50.0
Mini-pile foundation	X	X	X	X	X	X	X	X	0.0

Respondents of Cases 1, 2, 4, and 5, highlighted earth retaining technologies since deep excavations are involved in basement and pile caps in high rise building construction. A better earth retain technologies are required for high rise building construction, and the earth retains technologies applied in the selected cases are as follows: Steel Truss, Sheet piles, Secant piles, and Jet grouting wall.

4.3. *ANALYSIS OF INNOVATIVE TECHNOLOGIES ADOPTED IN SUPERSTRUCTURE PHASE*

Through a critical literature review, innovative technologies adopted in superstructure phase has been divided in to six (06) areas; i.e. Formwork, Hoisting and Working Platforms, Reinforcements, Concrete Work, Pumping, and Prefabricated Elements.

The literature identified that aluminium, fiber glass, plastic, crane operated climbing, system formwork (PERI system), and slip formwork, are used as innovative systems compared to the conventional timber/ plywood formworks. It could observe that Cases 1, 4, and 6, used aluminium formwork while other projects used plywood as formwork for general purposes. In addition, except Cases 5 and 6, all other projects have used system formwork as an advanced formwork system. Case 4 additionally used crane operated system formwork. One respondent from Case 5 stated that skilled workers can perform an equal work load in a lesser cost than with the use of system formwork.

Table 6 illustrates the findings of hoisting and working platforms, and depicts that working platforms are more popular than gondolas among the cases. It revealed that automated building construction systems (ABCS) are not yet practised, but Cases 1, 3 and 5 used semi-automated cranes during the construction. The interview personnel stated that the lifting weight and turning range were automatically controlled in these cranes. The luffing crane, which has ability to move horizontally and vertically, is more popular. In Case 3, CCTV cameras were located on top of the crane, which can be operated from the office. They were located to check the progress and ongoing work. The respondent of Case study 5 said that mobile cranes become a new trend, which can climb through core and work at top of the building.

Table 6: Innovative Technologies in Hoisting and Working Platforms

Innovative Technology	**Case 1**	**Case 2**	**Case 3**	**Case 4**	**Case 5**	**Case 6**	**Case 7**	**Case 8**	**%**
Gondola/Swinging Stage	√	X	X	X	√	√	X	X	37.5
Work platforms	√	X	X	√	√	√	X	X	50.0
Automated building construction system	X	X	X	X	X	X	X	X	0.0
Automated crane	√	X	√	X	√	X	X	X	37.5

Reinforcement bars area key material in high rise buildings. The study revealed that except Portable rebar tying tools, other types such as rebar cutter, reinforced bar bending machine, and Reinforced bar coupler in columns, have been used in all projects. Cases 1 and 7 used electrical bar bending machines and others used hydraulic bar bending machines, which have 3 times speed on average than manual. Moreover, the electrical portable rebar cutters were used instead of gas cutter. The respondents specified that bar couples in column becomes a popular technology, which reduced the lap length, and further it revealed that the cup lock scaffolding use 50% among these cases. The respondent in Case 3 stated that cup lock scaffoldings are speedy and need less labour for erecting and dismantling than conventional steel scaffolding.

A special concrete was used in high rise building construction, where self-compacting concrete and alternate for Portland cement concrete was commonly used. The projects that used self-compacting concrete (Cases 1, 2, 4, 5, and 7) identified that free compaction and high flow ability caused the popularity of self-compacting concrete in high rise building construction. The respondent of Case 4 said that self-compacting concrete is used for rebar in congested areas. Conversely, magnetically driven concrete and self-healing concrete are not practised well in the selected cases. However, light weight concrete was used in 75% of the projects. The Case 1 respondent indicated that reducing the structural weight of the building was the main aim of using light weight concrete. Carbon nano tubes are not used in these projects although they are a substitute for reinforced concrete. In addition, several cases used admixtures mixed concrete for specific purposes. Cases 1, 2, and 5 used ice mixed concrete to control the heat in concrete. Case 1 used accelerated admixture to speed up the hydrant of the concrete to speed erection. Case 3 used fly ash and silica fume for basement construction due to its high strength and water resist characteristics, while Case 5 used water proofing concrete as a water resistant purpose.

Table 7 present the findings of innovative technologies in concrete pumping systems. The findings emphasised that the stationary concrete pumps are the most popular type in these cases. Next was the truck mixture concrete pump. Case 4 used all three types of pumping systems, and its respondent said that pumping system need to be changed with the erected height of the building. According to his opinion, the truck mixture concrete pumps are the most suitable pumping method for the construction of foundation and basement. The stationary pumps are needed to pump concrete to a higher level. If the height could not be achieved by available stationary pumps, then the use of stage pumps becomes a necessity rather than changing to higher capacity stationary pumps. As stated by the respondents, the available equipment become ideal, and will impact the cost and time.

Table 7: Innovative Technologies in Pumping

Innovative Technology	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	%
Truck-mixture concrete pumps	√	√	√	√	X	√	√	√	87.5
Staged pumping	X	X	X	√	X	X	X	X	12.5
Stationary concrete pumps and booms	√	√	√	√	√	√	√	√	100.0

The next advanced technology was prefabrication elements, which have been used in 50% of the cases. Case 1 respondent stated that precast wall construction method “Eco-tec” is popular in Sri Lankan construction industry. It revealed that pre-tension concrete and contour crafting are not practised in the selected cases. Post-tension concrete elements are used in Cases 3 and 4. The respondent of Case 3 stated that the post-tension slabs are used due to less beam depth and optimum floor height with less thickness of slab. Therefore, in Case 3, the entire building received post-tension concrete slabs. However, Case 4 decided to adopt post-tension slabs for special requirements and thus, only one part adopted post-tension slabs to gain a large span with less columns. Cases 2 and 4 used sandwich panels as insulation. In Case 2, sandwich panels were used in the auditorium and to partition walls. The respondent of Case 4 explained that plastic spacers were used when placing structural precast element, because it facilitated perfect fixing.

4.4. ANALYSIS OF INNOVATIVE TECHNOLOGIES ADOPTED IN FINISHES PHASE

Table 8 illustrates the innovative technologies used for finishes work. According to the findings, power trowelling is the most popular floor finish. According to the respondent of Case 2, many high rise building projects tend to use power trowelling method due to less additional material, speed, and cost. Plastering machines and painting machines received 50%. Case 4 respondent explained that epoxy flooring was used for special requirements to gain an advanced finish. In addition, respondent of Case 3 stated that timber flooring to floor finishes and wall papers to wall finishes were applied. Case 5 used Wall claddings.

Table 8: Innovative Technologies in Finishes

Innovative Technology	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	%
Plastering machinery	X	√	X	√	√	X	√	X	50.0
Painting machines	√	X	X	√	√	√	X	X	50.0
Tiling machines	X	X	X	√	X	X	X	X	12.5
Epoxy flooring	√	X	X	√	X	X	√	X	37.5
Power Trowelling	√	√	√	√	√	√	√	√	100.0

4.5. BENEFITS AND CHALLENGES FOR CLIENT AND CONTRACTOR BY USING INNOVATIVE TECHNOLOGIES

The study identified identical benefits gained by the client and the contractor by using innovative technologies as follows:

- Time saving due to speed construction
- Cost reduction due to less wastage and less construction period
- Less additional material, labour, and equipment
- Proactive material covers more than one purpose
- High quality of work
- Less disputes between the parties due to proper communication
- Obtain optimum space as working space
- Special requirements can be fulfilled
- Waste reduction

On the other hand, challenges faced by client and contractor when using innovative technologies were identified through the opinions of respondents’:

- Higher initial cost premium
- Most of innovative plant and equipment are at higher costs
- Transport issues

It revealed that some innovative materials and plant required special permission to transport, because innovative materials and plant could not be categorized under existing categories in regulatory bodies. Therefore, it requires a special permit from authorities, and this process demand additional cost and time.

- Lack of operators or skilled labours and supervisors
- Innovative technologies are required for staff and labour training
- Insufficient suppliers and sub-contractors due to occasional usage of innovative plant and materials
- Heavy machinery requirements for several innovative technologies
- Need staff training, and that process need a longer period with additional costs

To adopt innovative technologies, it is pertinent to mitigate above challenges. Therefore, an organization needs to proceed after identifying internal and external impacts.

5. CONCLUSIONS

Most practising technologies were imported to local construction organizations from abroad, while some advanced technologies migrated with foreign organizations. The high technical and advanced technologies integrated with robotic are less practised in the construction industry. In addition, due to less skilled labour, some innovative technologies remain on the edge. Conversely, there is a possibility to apply those technologies in the construction industry with time. As the study revealed, innovative technologies could dominate the construction industry soon because the high rise buildings that can not be tackled through current practising technologies, are upcoming in Sri Lanka. Therefore, to survive and gain more benefits, it is necessary to adopt and encourage innovative technologies in local construction industry.

6. REFERENCES

Acuna, M. I. (2000). *Reducing time in the construction of high rise buildings.* Doctoral dissertation, Massachusetts Institute of Technology.

Ahn, H. Y., Pearce, R. A., & Wang, Y. (2013). Drivers and barriers of sustainable design and construction: The perception of green building g. *International Journal of Sustainable Building Technology and Urban Development, 4*(1), 35-45. doi:http://dx.doi.org/10.1080/2093761X.2012.759887

Allianz-Global-Corporate&Specialty. (2014). *Supertall Buildings Construction risk assessment in the 21st century.* Jonathan Tilburn, London: Allianz Global Corporate & Specialty.

Alshanbar, H. (2014). *Project Coordination Using Cloud-Based BIM Computing in Education.* Washinton: The building SMART alliance.

Arivazhagan, B. (2014). Automatic plastering machine. *Advanced Research in Electronics, Communication & Instrumentation Engineering and Development, 2*(2), 29-35.

Assaf, S., & Al-Hejji. (2006). Causes of delay in large cinstruction projects. *International Journal of Project Management, 24*(4), 349-357. doi:10.1016/J.ijproman.2005.11010

Benmansour, C., & Hogg, K. (2-4 September 2002). An investigation into the barriers to innovation and their relevance within the construction sector. In D. Greenwood (Ed.), *18th Annual ARCOM Conference. 2.* Northumbria: University of Northumbria.

Bock, T. (1998). *Automation and Robotics in Building Construction.* Munich,Germany: technische University.

Chen, J., Wang, J., & Jin, W.-l. (2016). Study of magnetically driven concrete. *Construction and Building Materials, 121*(1), 53-59.

Choi, Y., Kim, D. C., Kim, S. S., NAm, M. S., & Kim, T. H. (2013). Implementation of noise-free and vibration-free PHC screw piles on the basis of full-scale tests. *Journal of Construction Engineering and Management, 139*(8), 960-967.

Construction Industry in Sri Lanka. (2011). *Construction Industry in Sri Lanka.* Colombo: ICRA Lanka and IMaCS.

Creswell, J. W. (2014). *Research design : qualitative, quantitative, and mixed methods approaches.* (4, Ed.) New Delhi, India: SAGE Publications India Pvt. Ltd.

Dahlin, T., & Yngvesson, M. (2014). *Construction Methodology of Tubed Mega Frame Structures in High Rise Buildings.* Stockholm, Sweden: Master Thesis in Concrete Structures, Royal Institute of Technology.

Denagama, J., & Hadiwattege, C. (2013). *Development Supportive Novel Trends and Practices for Construction Sector.* Colombo: Department of Building Economics, University of Moratuwa, sri Lanka.

Dossick, C. S., & Simonen, K. (2014). *Integrated AEC studio: iteration between analysis and design for interdisciplinary learning.* Washington: The building SMART alliance.

Dubois, A., & Gadde, L. (2002). The construction industry as a loosey coupled system:Implications for productivity and innovation. *Construction Management and Economics, 20*(7), 621-631. doi:10.1080/01446190210163543

Egan, J. (1998). *Rethinking Construction.* London: Department of the Environment, Transport and the Regions.

Haowen, Y. (2015). Innovative Technologies and their Application on Construction of a 100-Plus-Story Skyscraper. *International Journal of High-Rise Building, 4*(3), 161-169.

Harrison, A. J. (2013, March). Low carbon cements and concrete in modern construction. In UKIERI. *Concrete Congress–Innovations in Concrete Construction*, pp. 723-746.

HING, L. C. (2006). *Construction technology for high rise buildings in Hong Kong* . Queensland: Doctoral dissertation, University of Southern Queensland.

Hirlekar, R., Yamagar, M., Garse, H., Vij, M., & Kadam, V. (2009). Caebon nanotubes and its application: a review. *Asian Journal of Pharmaceutical and Clinical Research, 2*(4), 17-27.

Hu, L. (2016). Analysis on Technological Innovation of Civil Engineering Construction. *Engineering, 8*(5), 287-291.

Ikeda, Y., & Harada, T. (2006). Application of the automated building construction system using the conventional construction method together . *23rd International Symposium on Automation and Robotics in Construction.* Tokyo, Japan.

Iwiss. (2008). *Electric rebar cutting and bending tools.* Iwiss Electric Co.Ltd. Retrieved from www.iwiss.com

Jonkers, H. M. (2011). *Bacteria-based self-healing concrete.* Heron, 56 (1/2).

Kang, T. K., Nam, C., Lee, U. K., Doh, N., & Park, G. T. (2011). Development of robotic-crane based automatic construction system for steel structures of high-rise buildings. *ISARC* (pp. 670-671). Seoul, Korea: ISARC.

Kavilkar, R., & Patil, S. (2014). Study of high rise residental building in Indian cities(A case study-Pune city). *International journal of Engineering and Technology, 6*(1), 86-90.

Khoshnevis, B. (2004). Automated construction by contour crafting -related robotics and Information Technology. *Automation in Construction, 13*(1), 5-19.

Kildienė, S., Zavadskas, E. K., & Tamošaitienė, J. (2014). Complex assessment model for advanced technology deployment. *Journal of civil engineering and management, 20*(2), 280-290. doi:doi:10.3846/13923730.2014.904813

Krishnan, L., Karthikeyan, S., Nathiya, S., & Suganya, K. (2014). Geopolymer concrete an eco-friendly construction material. Magnesium. *International Journal of Research in Engineering and Technology, 1*(1), 164-167.

Kyjakova, L., Mandicak, T., & Mesaros, P. (2014). Modern Methods of Constructions and Their Components. *Journal of Engineering and Architecture, 2*(1), 27-35.

Ling, F. (2003). Managing the implementation of construction innovations. *Construction Management And Economics, 21*(6), 635-649. doi:10.1080/0144619032000123725

Lloret, E., Shahab, A., Linus, M., Flatt, R., Gramazio, F., Kohle, M., & Langenberg, S. (2015). Complex concrete structures merging existing casting techniques with digital fabrication. *Computer-Aided Design, 60*, 40-49. doi:http://dx.doi.org/10.1016/j.cad.2014.02.011

McCuen, & Tamera. (2014). *The Challenges of Advancing BIM in the Curriculum while Addressing Current Accreditation Standards for Construction.* Washinton: The buildingSMART alliance.

Mehta, P. K. (1999). Advancements in concrete technology. *Concrete International -Detroit, 21*(1), 69-76.

Miyakawa, H., Ochiai, J., Oohata, K., & Shiokawa, T. (2000). *Application of Automated Building Construction System For High Rise Office Building.* isarc 2000-085_WB2.

Naguyen, T., & Chileshe, N. (2015). Revisiting the critical factors causing failure of construction projects in Vietnam . *Built Environment Project And Asset Mnagement, 5*(4), 398-416. doi:10.1108/bepam-10-2013-0042

Naji, B., Cottier, J. S., & lyons, R. (2005, May 17). *United States Patent No. US 6,893,751 B2.*

Navon, R., Rubinovitz, Y., & &Coffler, M. (1998). Rebar Computer Aided Design And Manufacturing. *Computer-Aided Civil and Infrastructure Engineering, 10*(6), 155-162.

Outokumpu. (2013). *Stainless Steel Reinforcing Bar Couplers.* Sheffield, United Kingdom: Outokumpu Stainless Ltd. Retrieved from www.outokumpu.com

Pan, Y., & Hou, L. (2016). Lifting and parallel lifting optimization by using sensitivity and fuzzy set for an earthmoving mechanism. (pp. 1-12). proceeding of the Institution of Mechanical Engineering. doi:DOI: 10.1177/0954407016660454

Prasanth, S. (n.d.). *Aluminium Form Work System.* Chenna: Grand Edifice Developers.

Puddicombe, M. (1997). Designers and Contractors: Impediments to Integration. *Journal Of Construction Engineering And Management, 123*(3), 245-252. doi:10.1061/0733-9364(1997)123:3(245)

Putzmeister. (2010). *Putzmeister Concrete Technology.* Germany: Putzmeister Concrete Pumps GmbH .

Richard, K. (1962). *Fiberglass Form Work.* , The Aberdeen Group.

Rosenberg, N. (2004). *Innovation And Economic Growth.* Stanford University, Economics. California: Stanford University.

Sakamota, S., & Mitsuoka, H. (1994). Totally Mechanized Construction System for High-Rise Buildings (T-UP System). In S. Sakamota, & A. D. Chamberlain (Ed.), *Automatic and Robotics in Construction XI* (p. 730). Boston: Newnes,2012.

Sandelin, C., & Budajev, E. (2013). *The Stabilization of High-rise Buildings: An Evaluation of the Tubed Mega Frame Concept.* Uppsala: Department of Engineering Science, Applied Mechanics, Civil Engineering, Uppsala University.

Schexnayder, C. J., & David, S. A. (2002). Past and Future of Construction Equipment-Part IV. *Journal of construction engineering and management, 128*(4), 279-286.

SGB-Group. (2005). *Cup Lock Scafold User Guide.* Leatherhead, Surrey: SGB Services Limited. Retrieved from www.sgb.co.uk

Shin, Y., Kim, T., Cho, H., & Kang, K. I. (2012). A formwork method selection model based on boosted decision trees in tall. *Automation in Construction, 23*(1), 47-54.

Slaughter, E. (1998). Models of Construction Innovation. *Journal Of Construction Engineering And Management, 124*(3), 226-231. doi:10.1061/(asce)0733-9364(1998)124:3(226)

Tatum, C. B., Vorster, M., & Klingler, M. (2006). Innovations in earthmoving equipment: new forms and their evolution. *Journal of construction engineering and management, 132(9), 987-997., 132*(9), 987-997.

Thapa, C., Dhakal, D. R., & Dhakal, A. (2013). Construction Techniques and Demand Of High Rise Building In India. *International Journal of Emerging Trends in Engineering and Development, 2*(3), 46-51.

Thillairaja, S., Varun Yadav, K., VelMuruga, G., Venkatesan, S. P., Prabhakar, K., & Kumar, R. (2015). Reinforced bar bending machine. *Australian Journal of Basic and Applied Sciences, 9*(10), 290-294. Retrieved from www.ajbasweb.com

Vähä, P., Heikkilä, T., Kilpeläinen, P., Järviluoma, M., & Heikkilä, R. (2013). *Survey on automation of the building construction and building products industry.* Oulu: JULKAISIJA – UTGIVARE.

Väha, P., Heikkilä, T., & Kilpeläin, P. (2013). Extending automation of building construction — Survey on potential. *Automation in Construction, 36*(1), 168-178.

Vennstrom, A., & Eriksson, P. (2010). Client perceived barriers o change of construction process. *Construction innovtion: information, process, management, 10*(2), 126-137. doi:10.1108/14714171011037156

Vivian, W., Ivan, W. F., & Michael, C. (2015). Best practice of prefabrication implementation in the Hong Kong public and private sectors. *Journal of Cleaner Production, 109*(1), 216-231.

Warszawski, A., & Navon, R. (1998). Implementation of Robotics in Building: Current Status and Future Prospects. *Journal Of Construction Engineering And Management, 124*(1), 31-41. doi:10.1061/(asce)0733-9364(1998)124:1(31)

Wells, J. (1985). *The construction industry in the context of development* (Vol. 8). London: Pegamon Press Ltd.

Winch, G. (2003). How innovative is construction? Comparing aggregated data on construction innovation and other sectors – a case of apples and pears. *Construction Management And Economics, 21*(6), 651-654. doi:10.1080/0144619032000113708

Yehia, S., Douba, A., Abdullahi, O., & Farrag, S. (2016). Mechanical and durability evaluation of fiber-reinforced self-compacting. *Construction and Building Materials, 121*(1), 120-133.

Yu, K., Guan, Z. J., Cheung, T., T. T., & Lo, T. (2000). Applied Radiation and Isotopes. *Light weight concrete: 226Ra, 232Th, 40K contents and dose reduction assessment*, *53*(6), 975-980.