Framework on the Barriers to the Implementation of Automation and Robotics in the Construction Industry

Rohana Mahbub
Faculty of Architecture, Planning and Surveying, Universiti Teknologi MARA, Malaysia
rohana.mahbub@yahoo.com
*Corresponding Author

Received 3 April 2015; received in revised form 16 June 2015; accepted 30 June 2015

Abstract

Most countries have seen a rise in the use of innovative technologies in the construction industry, mostly in an attempt to address associated problems, such as decreasing quality and productivity, labour shortages, occupational safety, and inferior working conditions, especially on construction sites. One option is in the implementation of automation and robotics technologies, which have the potential to improve the industry in terms of productivity, safety and quality. However, this may not be suited to all countries. The research aim was to ascertain and explain the barriers to construction automation and robotics' implementation by exploring and establishing the barrier variables, the relationship between characteristics of the construction industry and the attributes of existing technologies in the form of ranking schemes based on data from three countries, Japan, Australia and Malaysia. Detailed quantitative (statistical) and qualitative (content) data analysis was performed, including cross-tabulations, and bivariate and multivariate analysis for investigating possible relationships between variables. In addition, the Kruskal-Wallis and Mann-Whitney U test of independent samples were used for hypothesis testing and for inferring the research sample to the construction industry population. A framework of ranking schemes produced for four key areas of, the construction attributes on level of usage; barrier variables; differing levels of usage between countries; and future trends, have established a number of potential areas that could have an impact on the level of implementation, both globally and for individual countries. The framework was also tested and validated on data from the Singaporean construction industry.

Keywords: Barriers to implementation, automation and robotics, construction industry

1. Introduction

Today, the use of innovative technologies has permeated across industries in most countries, including the construction industry. This is especially relevant for countries where the construction output is growing exceedingly fast due to high demands for infrastructure and buildings needed for development and growth of the nation. These newly industrialized countries, or NICs, are nations with economies more advanced and developed than those in the developing world, but without yet the full signs of a developed country, such as China or Malaysia. These economies have, in some cases, more than doubled their share of construction output and development, creating a rapidly developing industry that is bursting at the seams, and in need of more efficient and innovative solutions to increase productivity and the quality of the work produced (Bozyk, 2006; Mahbub, 2012).

As more countries embrace industrialization and the use of innovative technologies in their construction industry to address increasing demand and rising construction output, sometimes through the support of strong government policies, it is important to investigate how the countries' capabilities and characteristics fit in with the attributes of the technologies and the barriers to implementation so as to measure their state of readiness. This paper describes a framework of ranking schemes that can be used to examine the state of readiness of countries intending to use automation and robotics technologies, specifically in terms of their construction attributes on level of usage; the barrier variables and differing levels of usage to gauge the relevancy of the technologies to the organizations and the countries in general. The framework could be useful in gauging the level of readiness based on core factors identified within the framework that may assist countries in finding the platform on which areas or technologies are most suited, given the countries' characteristics. The framework was produced initially based on data from three countries, Australia, Japan and Malaysia, and will subsequently be further developed using data from other countries, such as Singapore, China, Indonesia, Thailand, the Philippines and India.

2. Literature Review

The basis of the literature review for this research was to critically establish the extent and depth of existing knowledge on construction automation and robotics technologies in terms of definitions, range of technologies and the level of global implementation. The main characteristics of the construction industry and the likely automation and robotics technologies to be used throughout a construction project, from design to on-site application, were also examined to further explore the correlation and collaborate the relevancy of automation and robotics technologies to the construction industry. The issues underpinning the two key factors "construction characteristics" and "automation and robotics" can then be evaluated and investigated to produce the "barrier factors".

2.1 Construction Automation and Robotics Technologies

For this research, *construction automation and robotics* is defined as self-governing mechanical and electronic devices that utilize intelligent controls to carry out construction tasks and operations automatically. The construction work tasks and operations are regulated through programmable controls and sensors which are set up as a series of individual computer-controlled or robotic equipment with electro-mechanical links. (Mahbub, 2008)

Investigating ways where technologies can be adopted more easily in relation to the work process already in place can assist in identifying the areas where automation and robotics, in all probability, will be most relevant. These technology areas may include phases of construction, such as adopting a greater percentage of innovative technologies during the design phase, as compared to the construction phase, or it could be in terms of the construction process itself. Some construction processes, such as the installation of building components, are easier to automate as opposed to substructure or building foundation works. In this case, the drive to innovate is facilitated by the relatively straightforward technological processes that are already in place within this area. It can be construed from the characteristics and the overlapping of traditional and new technologies in terms of technology fusion that the prospect for implementation of automation and robotics technologies during the on-site phase of construction may be more widespread for some stages of the construction process compared to others (Hasegawa, 2006; Kajima, 2015; Obayashi, 2015; Shimizu, 2015 and Takenaka, 2015). However, these factors should not be looked at in isolation as other phases of a construction project, such as design, also play an important role in facilitating the adaptation of these technologies on the work site. For on-site construction, the six main stages identified that have the most potential for automation and robotics implementation were earthworks, structural steelwork, concreting, building assembly/lifting and positioning of components, painting/ finishing, and total automation of the construction works, which involves the whole building process (Mahbub, 2012, IAARC, 2015).

2.2 The Construction Industry and the Global Development of Automation and Robotics Technologies

A shortage of labour is one of the factors behind the drive in many countries to mechanize production, by shifting from traditional craft methods to production of components in factories through prefabrication. This makes sense in economies where full employment is creating upward pressures on wages, or where labour shortages are acute.

Japan can be considered as the world leader in construction technology based on two interrelated factors: (1) the efforts toward technological innovation through research and development (R&D); and (2) a large domestic market and internalization of demand from Japanese investors in foreign countries. During the 90s, construction automation and robotics R&D activities were led by Japanese companies and universities, and were focused on the development of new robotic systems and in the automation of existing machinery. Nowadays, the focus is more on software and IT technologies, including on-site sensory data acquisition and processing, human operators' field safety and security, chip-based process controls, monitoring and many other aspects (Balaguer and Abderrahim, 2008).

In emerging economies, such as Malaysia, the need to improve the performance of the construction industry and address inherent problems, such as productivity and workmanship performance, inefficient construction processes and delivery, poor quality materials and products, ineffective organisation and supply chain management, have pushed forward the adoption of new construction methods and technologies in the industry. This has paved the way for the increasing use of innovative technologies in the Malaysian construction industry, as addressed under the Construction Industry Master Plan Strategic Thrust 5. This plan includes encouraging the use of industrialised building systems (IBS) and prefabrication, building information modelling (BIM), mechanisation, automation and robotics, and to a certain extent, modular construction (CIDB, 2015). R&D is mostly carried out by universities in Malaysia, sometimes in collaboration with the industry, and by CREAM, the R&D arm of the Construction Industry Development Board of Malaysia (CREAM, 2015).

3. Research Methodology

In the initial phase of the research, the barriers to implementation were investigated for Japan, Australia and Malaysia. These three countries were chosen because their construction industry characteristics provide a contrast in terms of culture, gross domestic product, technology application, organisational structure and labour policies. These countries also demonstrate a wide spectrum in terms of technology application, from high usage in a developed country (Japan), low usage in a developed country (Australia) and fairly low usage in a developing country (Malaysia). This phenomenon and the differing characteristics provide the general framework and were used to form the ranking schemes that would explore the different levels of implementation of automation and robotics globally.

This research adopted a mixed method approach of gathering data, both quantitative and qualitative, by using a questionnaire survey and an interview schedule to investigate respondents' attitudes towards the usage of automation and robotics in their construction firms. An Attitudinal Scale was developed following the Summated Rating or Likert Scale of five and seven-point numerical scales. A questionnaire was developed and distributed to construction firms, targeting contractors, specialist sub-contractors, developers and consultants to determine the extent of use and related value of the technologies. These companies were asked to provide input regarding industry perception, benefits, barriers, and suggested practices for implementing construction automation and robotics technologies. The type chosen was a closed questionnaire, divided into five main sections: demographic information; the level of implementation and development of automation and robotics technologies; issues and concerns pertaining to the use of automation and robotics technologies; perceived barriers and their impact; and future trends and opportunities.

For any research, the required sample size depends on two key factors: the degree of accuracy required for the sample and the extent to which there is variation in the population with regards to the key characteristics of the study. Other than accuracy, cost and time are key factors in working out the sample size. Taking into consideration the large geographical area covered for the research, and the inherent cost and time implications, the sample size for the questionnaire survey of this research was selected to be 80 for each country, with a total number of 240 construction companies in the sample group. This was based on judgement sampling of the top 80 companies operating in the Japanese, Australian and Malaysian construction industries, specifically contractors, specialist sub-contractors, developers and consultants. Also, due to the large geographical area covered involving the three countries of Japan, Malaysia and Australia, it was found that mail only questionnaires would be impractical. Therefore, the respondents were given the option of either responding by mail, or through a web-site. The web questionnaire was designed to be as user-friendly as possible - respondents were required to "scroll down, click and point" to select the appropriate response to each question; before submitting the completed questionnaire directly via e-mail by clicking the "submit" button. The questionnaire for each country was separated on different web pages to facilitate data coding, handling and analysis. The total response rate was 105 (44%) with 48% from Australia, 29% from Japan and 23% from Malaysia.

The interviews conducted were semi-structured and one-to-one to allow for additional probing and the opportunity to gather more in-depth information on the subject in order to supplement the data gathered from the questionnaire. Due to the geographical distribution of the study population, the sample size for the interviews was relatively small, about 7 per country, with a total number of 21; as a larger sample might prove to be expensive and inconvenient. The results of the interviews were used to support and cross-validate the questionnaire findings. This research therefore employed the mixed methods strategy where data were collected sequentially, with the questionnaire survey providing a broad information base, whilst the interviews provided a specific focus on certain characteristics or areas, specifically the factor regarding barriers to implementation. A summary of the demographic information of the sample is depicted in Table 1 below.

In administrating both the questionnaire and interview, English was used for all three countries. In Malaysia, as English is spoken widely, there were no critical issues for respondents in understanding the questions. However, for Japan, to address this, the respondents were also given the option of whether they would prefer the language to be Japanese. Additionally, in cross-cultural data collection, there were also other issues to be considered, especially in terms of relationships and social frameworks, time and power distance (Reynolds and Valentine, 2004).

Table 1: Summary of the Demographic Information of the Sample

VARIABLES	GROUPING	JAPAN (FREQ %)	MALAYSIA (FREQ %)	AUSTRALIA FREQ %)
Business Type	Contractor	40	38	55
	Sub-contractor	7	8	7
	Consultant	43	16	27
	Developer	10	38	11
Sector of Industry	Residential	10	25	5
	Non-residential	0	0	34
	Civil engineering Works and Infrastructure	20	25	12
	All of the Above	60	38	34
	Residential & Non-residential Only	10	12	15
Number of Full-time Staff	1-50 people	0	26	8
	51-100 people	3	12	6
	101-250 people	3	8	23
	251-500 people	33	21	27
	501-1000 people	33	21	26
	More than 1000 people	28	12	10
Number of Branches Outside the Country	None	30	90	78
	1-5	40	10	4
	6-10	20	0	18
	16-20	10	0	0

In Australia, people place great importance on individuality, independence and self-reliance, and therefore communication tends to be direct, explicit and personal. In contrast, collectivism is common in most Asian countries, such as Japan and Malaysia, and in this context communication tends to be intuitive, complex and impressionistic, and attention should be given to implicit, non-verbal messages and body language. The order in which information is presented is also different. In Western cultures, important information tends to be given first, with less important items left towards the end, whilst in Asian cultures, less important items are spoken of first, setting the stage for the important information, which comes at the end. To ensure the reliability of the data collected in terms of cultural differences, there is a need for sensitivity on the part of the interviewer, especially in reconfirming points that have been raised but have not been directly disagreed upon.

The need to maintain reliability and validity throughout the research process so as to ensure all the components of the research being conducted measured up to the elements under study; and to make certain the most suitable methods, instruments, techniques and procedures have been selected and implemented, were addressed through several means including conducting pre-testing and a pilot study. Pre-testing addresses the face and content validity whilst the pilot study, to a certain extent, addresses the criterion validity of the research. A pilot study was carried out for a small sample of 75 i.e. 25 for each country, and the response rate was 35%. Improvements were made to the research instrument based on the pilot study, including the method of administering the questionnaire to improve response rate (by including a website option in the actual survey) and the minor re-phrasing of items to improve comprehension. The internal reliability of the research instrument was also assessed using Cronbach's Alpha (α), which is an index of reliability associated with the variation accounted for by the true score of the underlying construct. The values of Cronbach's Alpha for all related items in the questionnaire were duly computed and analyzed; and the value for the total items at 0.875 and 0.894 indicated high internal consistency of the instrument.

The findings from the survey were useful in providing a better understanding of the range and level of construction automation and robotics technologies that are currently in use and in ascertaining a pattern of usage for the three selected countries, Australia, Japan and Malaysia. This was then used to develop a framework to further investigate the barrier variables under study based on the characteristics of the technologies in use, the three countries' construction industries and their patterns of implementation.

4. Data Analysis and Findings

Data becomes meaningful only after analysis has provided a set of descriptions, relationships, and differences that are of use in addressing the research objectives. In the case of this research, the purpose of data analysis was both to uncover phenomena that may describe or be related to a situation in some way, such as looking at the possible relationship between the level of use of automation and robotics and the size of company (cross-tabulations, bivariate and multivariate analysis), and relating the research sample to the construction industry population of Japan, Malaysia and Australia (inferential statistics and hypothesis testing; through tests conducted such as Kruskal-Wallis and Mann Whitney U test of independent samples). The two data sets analysed under Phase 1 (the questionnaire) and Phase 2 (the interviews) were then integrated in that the findings from phase two were used to elaborate and extend the analysis results of phase one. The process of synthesizing and integrating the results of both phases were discussed and placed in context with the literature review concerning barriers to the implementation of automation and robotics in construction.

4.1 Questionnaires

For the questionnaire data, numerical measures of location and variability using mean and standard deviation were only applied on a limited basis to the analysis of the interval variables in the demography section, whereas descriptive statistics in the forms of graphical presentations and tables (frequency distributions) were employed more extensively. Frequency counts were used for univariate analyses of the variables whilst cross-tabulations were used for bivariate or multivariate analyses of the variables involving nominal or ordinal scales. The other frequently used analysis for this research was inferential statistics in the form of non-parametric tests, such as the Kruskal-Wallis and Mann-Whitney U-statistic tests. As the frequencies represent ordinal measurements with many points on the scale, the Kruskal-Wallis test, a rank-order test of significance, was used to interpret the data. Cases were ordered from lowest to highest according to the "score" each case received on the scale, and then assigned a ranking that indicated where in the list it appeared. Here, the descriptive statistics for the ranking of the means were performed using the Kruskal-Wallis test for the three country sample, and the results are as shown in Tables 4 and 5. The Mann-Whitney U test was then performed as an independent check and to cross-validate the results from Kruskal-Wallis. The statistical analysis for the questionnaire data was performed using SPSS (Statistical Package for the Social Sciences) software.

4.2 Interviews

The analysis of qualitative data in Phase 2 was facilitated by the use of NUD*IST (Non-numerical Unstructured Data Indexing Searching and Theorizing) Vivo. The document file holds all the documentary data and interview transcripts, as well as memos regarding these. The nodes represent categories of data that are important to the research project, and memos of the researcher's ideas can be attached to these. (Richards, 2005; Richards, 2006). For this research, the categories were mainly coded under Tree Nodes (stored in hierarchical catalogues) and Cases. The categories that emerged from the code note headings of the interviews formed the basic framework that constituted core materials for answering this study's research questions. The core materials for analysis were formed by comments and notes categorised under these headings, which were found to be useful in explaining or interpreting the findings of the research.

4.3 Analysis of Data

This paper will describe only selected areas of the quantitative and qualitative data analysis that are useful in highlighting the development of the framework of ranking schemes for the implementation of automation and robotics technologies.

4.3.1 Area of Implementation

The majority (90%) of Japanese companies used automation and robotics, whilst in Australia, 65% used the technology and 50% in Malaysia. However, a more useful indication would be to look at the areas within which the technologies are used, as most of the companies may only use automation at the design stage in the form of design software, such as Computer Aided Design (refer to Figure 1).

Overall, Japan used the technology across the board, although with less usage in on-site construction compared to the other areas. However, there was still a greater percentage of on-site application in Japan (on-site usage: Japan 70%, Malaysia 12% and Australia 22%), compared to Malaysia and Australia. The prevalent areas of usage for Malaysia and Australia are in scheduling/planning, design and costing/tendering, with some applications in project management. Australia, however, used the technology slightly more on-site compared to Malaysia.

4.3.2 Why the Technologies are Used More Predominantly in Certain Areas of Construction

This question involved respondents choosing what, in their opinion, are the reasons automation and robotics are used more predominantly in certain areas of construction, such as design, but not others. The most popular reason chosen by respondents at 24% was that the type of work done by the company reflects the areas of usage.

Table 2: Reason for Use in Certain Areas

Why used predominantly in certain areas?	Frequency of Use
Type of work done by company reflects areas of usage	48(24%)
High costs associated with application in certain areas	30(15%)
Availability of technologies differs across the areas	36(18%)
Ease of use (easily understood during implementation)	27(14%)
The technologies can be used repetitively for a range of projects	27(14%)
Differing levels of awareness (exposure) across areas	30(15%)

4.3.3 Perceived Barriers to Construction Implementation

The barriers to implementation are interconnected with a number of factors, including the main problems associated with technology use and areas of usage within the construction phases. For the questionnaire, a list of eight statements relating to barriers to implementation was provided and respondents were requested to indicate their opinion of each statement ranging from the least to the most significant. The variable and value label codes and summary of analysis results for the statistical analysis are presented in Tables 3 and 6, whilst the results of the content analysis are presented in Table 7 below.

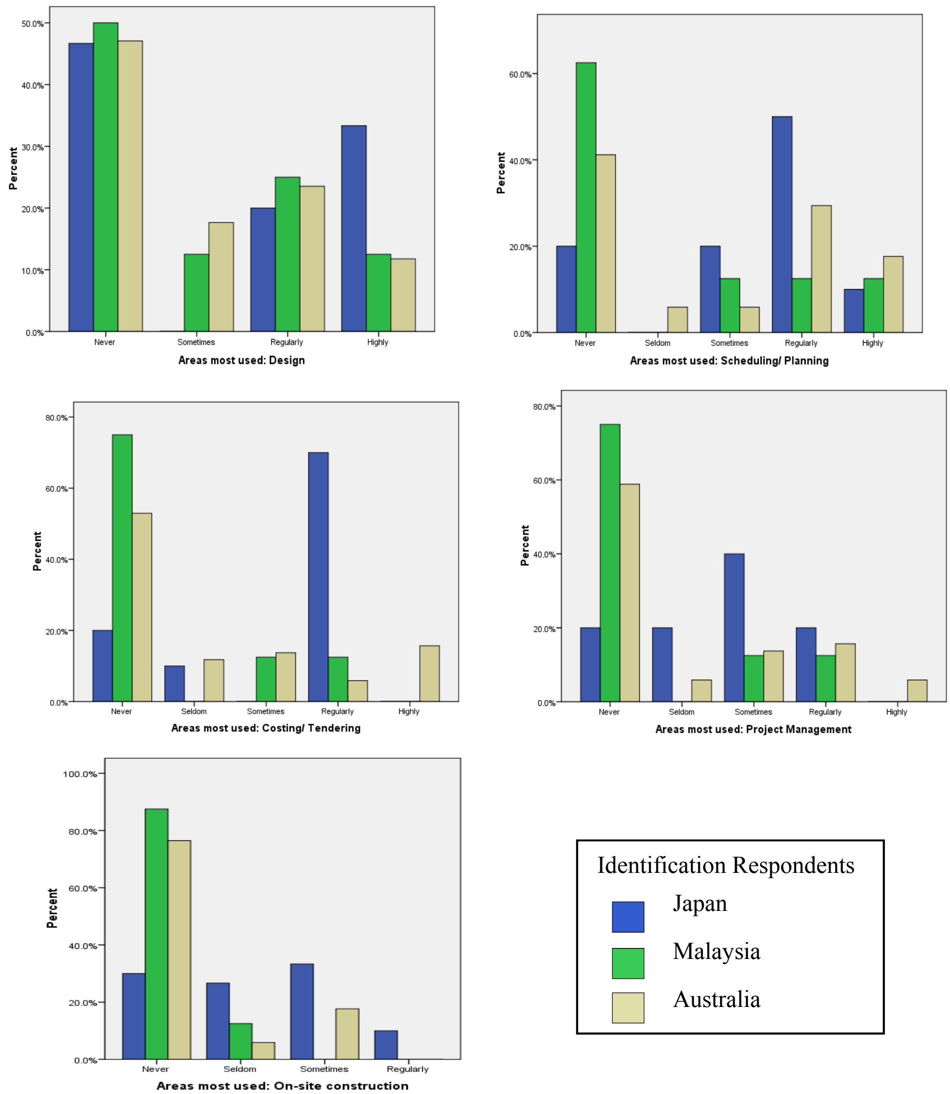

Figure 1: Level of Use of Automation and Robotics Technologies in Different Areas of Construction (Design, Scheduling and Planning, Costing and Tendering, Project Management and On-site Construction)

Table 3: Variable Codes and Description

Code	Variable Description of Barriers: Questionnaire statement
B1	High costs / substantial financial commitment in acquiring the technologies
B2	Automation and robotics technologies are expensive to update and maintain
B3	Incompatibility of the technologies with existing practices and current construction operations.
B4	The fragmentary nature and size of the construction industry makes the technologies difficult to implement
B5	Automation and robotics technologies are difficult to use and not easily understood
B6	Automation and robotics technologies are unavailable locally or difficult to acquire
B7	The technologies are not easily accepted by the workers and workers' union
B8	Low technology literacy of project participants / need for the re-training of workers

Table 4: Barrier Variables: Kruskal-Wallis Test Statistics and Descriptive Statistics

DESCRIPTIVE STATISTICS							**TEST STATISTICS GROUPING: COUNTRIES**		
Variable	N	Mean	Rank	Std. Dev.	Min	Max	Chi-square	*df*	Asymptotic Significance (2-tailed)
B1: Cost to acquire	105	4.69	1	1.625	1	7	1.800	2	.407
B4: Fragmented	105	4.29	2	1.392	1	6	9.652	2	.008
B5: Difficult to use	105	4.03	3	1.348	1	6	4.499	2	.105
B2: Cost to update	105	3.97	4	1.213	1	6	16.374	2	.000
B3: Incompatible	105	3.97	4	1.390	1	6	2.362	2	.307
B8: Low literacy	105	3.83	6	1.471	1	7	17.826	2	.000
B6: Unavailable	105	3.71	7	1.758	1	7	19.439	2	.000
B7: Not accepted	105	3.60	8	1.685	1	7	26.208	2	.000

Table 5: Barrier Variables: Kruskal-Wallis Test and Mean Ranks

VARIABLE	COUNTRY	N	MEAN RANK	VARIABLE	COUNTRY	N	MEAN RANK
B1:	1 Japan	30	56.15	B5:	1 Japan	30	60.95
Cost to ac-	2 Malaysia	24	57.50	Difficult to	2 Malaysia	24	43.81
quire	3 Australia	51	49.03	use	3 Australia	51	52.65
B2:	1 Japan	30	71.30	B6:	1 Japan	30	32.90
Cost to up-	2 Malaysia	24	46.81	Unavailable	2 Malaysia	24	57.31
date	3 Australia	51	45.15		3 Australia	51	62.79
B3:	1 Japan	30	45.95	B7:	1 Japan	30	35.00
Incompatible	2 Malaysia	24	56.00	Not accepted	2 Malaysia	24	43.44
	3 Australia	51	55.74		3 Australia	51	68.09
B4:	1 Japan	30	51.65	B8:	1 Japan	30	34.70
Fragmented	2 Malaysia	24	38.00	Low literacy	2 Malaysia	24	53.94
	3 Australia	51	60.85		3 Australia	51	63.32

Table 6: Barrier Variables: Summary of Analysis Results

Variable	**Descriptive Statistics**			***Accept***	
	Rank	**Mean**	**Std. Dev.**	H_O	H_A
B1: CostAcq	1	4.69	1.625	√	
B4: Fragment	2	4.29	1.392		√
B5: Difficult	3	4.03	1.348	√	
B2: CostUpd	4	3.97	1.213		√
B3: Incomp	4	3.97	1.390	√	
B8: Low Lit	6	3.83	1.471		√
B6: Unavail	7	3.71	1.758		√
B7: NotAccpt	8	3.60	1.685		√

For the interviews (Table 7), almost all participants (92.1%) agreed that the barriers are very much influenced by the different phases of construction, with the majority agreeing that barriers to automation and robotics technologies being implemented within on-site construction are much greater compared to barriers to implementation during the design phase. With regards to cost, the wider scope of the quantitative analysis that separated initial and updating costs was consolidated and incorporated under one variable, i.e. "cost", after triangulation with the qualitative results and the literature.

Table 7: Summary of Content Analysis: Barrier Variables

Rank	Barrier variables	Freq.	% of Response	
			Positive	Negative
1	Different Construction Area Usage	43	92.1	7.9
2	Cost	39	87.7	12.3
3	Fragmented Industry	28	72.6	27.4
4	Difficult to Use	23	58.5	41.5
5	Incompatibility	18	57.3	42.7
6	Re-training	15	48.0	52.0
7	Unavailable	11	50.3	49.7
8	Not accepted	8	32.9	67.1

4.4 Framework of Ranking Schemes for the Core Factors

The main categories reviewed pertaining to the technologies implementation were economics and cost, structure or organisation, products and processes, technology, and culture or human factors; which were then elaborated in parallel to the construction characteristics and barrier variables. Through the research instruments, namely the questionnaire and interviews, and the data collected, analysed and synthesised with the literature, a simple framework of ranking schemes was developed which incorporated the key factors and variables that had been identified. This framework allowed for the comparison and ranking of these factors and variables in terms of their application or significance.

4.4.1 Ranking Scheme 1: Correlation between the Characteristics of the Construction Companies and Industry to the Level of On-site Usage of Automation and Robotics Technologies

Areas of construction play a significant role in influencing levels of usage, with the core factors under investigation showing a stronger correlation with the level of usage for on-site construction, when compared to other stages, such as design. As such, it can be deduced from statistical evidence that there is no significant relationship between the level of implementation and the core factors for the earlier stages of construction, especially in design and planning/scheduling. Following these facts, the ranking scheme produced below is applicable specifically for on-site construction only, as this area is also the main focus or scope of the research.

Table 8: Ranking Scheme 1: Correlation Between Core Factors and Level of Usage

Ranking	Characteristics of Company and Industry
1	Size of Company
2	Type of Business
3	Market Share
4	Construction Sector

4.4.2 Ranking Scheme 2: Barrier Variables

One important aspect that was ascertained from the examination of the barrier variables was that the ranking of all seven variables corresponds with each other for both the statistical and content analyses. Another aspect that should be mentioned is that the barrier variables were, again, very much related to the areas of usage, but as far as possible, the ranking scheme produced for this area is specific to on-site construction.

Table 9: Ranking Scheme 2: Barrier Variables

Ranking	Barrier Variables
1	High Costs / Financial Commitment
2	Fragmented Nature of the Construction Industry
3	Difficult To Use/Not Easily Understood
4	Incompatibility With Existing Practices and Current Construction Operations
5	Low Technology Literacy of Project Participants/Need For Re-Training Of Workers
6	Unavailable Locally and Difficult to Acquire
7	Not Accepted By Workers

From the ranking scheme, it can be concluded that the high costs and financial commitment associated with automation and robotics application is the most significant factor whilst the least significant is the technologies not being accepted by workers. It can be deduced from this that the construction industry is fairly cost sensitive towards technology utilisation, and for there to be greater implementation of the technologies, the purchase, operating and maintenance costs need to be affordable and offered at a more competitive price to the industry.

4.4.3 Ranking Scheme 3: Comparison of Differing Levels of Usage between Countries

The differing levels of usage of the technologies were investigated between Japan, Malaysia and Australia for comparison purposes; evolving around six core factors including: the individual countries' construction characteristics; the labour situation; cultural and societal acceptance of the technologies in general; companies' market share composition; government and company policies; and the countries' construction management and workers' unions.

In answering the question of "why there is a greater use of the technologies in one country compared to another", no attempt was made to rank these factors and only a list of reasons were provided as it was deemed as more suitable in answering "why" a phenomenon occurs. The ranking scheme provided here is based on the content analysis ranking derived from the three sample countries.

Table 10: Ranking Scheme 3: Comparison of Differing Levels of Usage between Countries

Ranking	Core Factors Influencing Level Of Usage Between Countries
1	Construction Characteristics
2	Labour Situation
3	Cultural and Societal Acceptance of Technologies
4	Companies' Market Share Composition
5	Government and Company Policies
6	Construction Management and Workers' Union

Construction characteristics play a vital role in determining the level of implementation of the technologies, as can be deduced from the higher level of usage by the Japanese. The Japanese construction industry comprises mostly of large conglomerates operating under one roof and involved in fairly large and competitive markets; compared to Malaysia and Australia where the construction industry comprises of fairly small businesses.

4.4.4 Ranking Scheme 4: Future Trends and Opportunities

The future trends and opportunities were statistically analysed under a broader group of ten categories whilst the content analysis provided a focus by directing the topic area into a smaller group of five categories. However, for ranking purposes, the statistical analysis will be used so as to provide a broader information base and better clarity in terms of the significance placed by the participants on each trend stated.

It can be concluded from the ranking scheme that an increasing awareness of the technologies within the construction industry community is the most probable future scenario for automation and robotics technologies. The least likely scenario, of there being greater integration within the construction industry, is to be expected and is generally supported by literature evidence. As the industry is usually composed of small companies specializing in different areas of construction; with different responsibilities and control within their own area, it is very unlikely that we will see greater integration within these smaller companies in the near future.

Table 11: Ranking Scheme 4: Future Trends and Opportunities

Ranking	Future Trends and Opportunities
1	Greater awareness of the technologies within the construction industry community
2	The number of construction companies using automation and robotics technologies will increase significantly
3	Automation and robotics technologies will be cheaper to acquire and operate
4	There will be a significantly larger range of automation and robotics technologies available for use in construction
5	There will be greater standardisation of the design and construction processes
6	The use of automation and robotics technologies will enable firms to operate more efficiently and competitively
7	The technologies will be easily available across the world
8	The technologies will be readily accepted by the workers and the industry
9	Automation and robotics technologies will be easier to install and operate
10	There will be greater integration within the construction industry in terms of control and responsibility for design and construction

4.4.5 Discussion on the Findings

The contributions made through the ranking of the key categories identified within the four areas were realised in terms of establishing the groundwork for research on the global application of construction automation and robotics technologies. The key categories identified under ranking schemes 1 and 3 can be employed to determine the potential for any country in terms of adopting the technologies; in that the schemes can be used to gauge whether a country is more likely to use the technologies based on their construction industry attributes.

For example, these ranking schemes can be used to investigate which country is more likely to adopt such technologies, for instance Yemen or Singapore, given the characteristics of the construction industry in each country and the foreseeable advantages to be gained in adopting the technologies.

Ranking scheme 1 can be employed to gain a better understanding of the construction companies' composition in these countries with regard to the technologies. In Yemen, the construction industry is mostly made up of small companies operating in a fairly localised market, so the ranking for its potential use of technologies would be fairly low. These facts can then be juxtaposed with ranking scheme 3, and it is found that the labour costs in Yemen are quite low, with less cultural and societal acceptance of technologies in general. Therefore, it can be concluded that Yemen rates low in terms of the adoption of the technologies. The same procedure can be applied to Singapore, and from there the rankings can be used to determine whether the potential for the technologies' adoption by each country is ranked high or low, whilst allowing comparisons to be made.

To be more precise and to provide better clarity, the ranking schemes need to be expanded to allow for weightage of rankings between countries to be evaluated, which is an area for future research work.

Ranking scheme 2 can be used to investigate the barriers to implementation for a country that is found to be likely to adopt the technology but currently is not. As evidenced by the findings of the literature, for some countries, the best solutions to their labour or other construction problems are not seen to be the adoption of innovative technologies, especially if there are high costs involved. The ranking scheme can allow researchers to study the reasons why these technologies are not used, and if it is generally because of high costs or unavailability, there may be potential in examining selected areas of use where these barriers do not present such a high level of hindrance. Ranking scheme 4 can provide the researcher with the background on the predicted value and use of the technologies in the future. Where there is an area that is discovered to gain advantages from the use of the technologies, then future trends can assist in predicting the likely scenario of the technologies' application in these areas. A summary of the framework of the ranking schemes is shown in Figure 2.

5. Current and Future Research

In order to test, validate and build the database for the framework of ranking schemes, subsequent research data was collected from Singapore, via an on-line questionnaire distributed in January 2014. Preliminary analysis of the research data from Singapore has indicated that the results correspond with the factors under the framework of ranking schemes as previously described. For research on Singapore and other subsequent target countries such as Indonesia, China, Thailand and India, the focus will be on core factors under ranking schemes 1, 2 and 3 only; as it is within these areas that the framework would be most applicable and useful for gauging the level of use of automation and technologies globally.

6. Conclusions

From the literature and analytical data findings, there is clear evidence that the implementation of automation and robotics in the construction industry is influenced by the characteristics of the construction industry and the attributes of individual companies in parallel to consideration of their barrier variables. Findings and conclusions arising from the research work, including the ranking schemes produced for the four key areas of construction attributes on the level of usage, barrier variables, differing levels of usage between countries, and future trends, have established a number of potential areas for further research that could have an impact on the level of implementation both globally and for individual countries. The research also sets out and provides various perspectives of the construction industry and advanced technology applications from the three countries studied, namely Japan, Malaysia and Australia. This establishes the groundwork for further research into the global application of automation and robotics technologies; in terms of extending the ranking schemes to address a wider application and expanding the database to include countries such as Singapore, Indonesia, China, Thailand and India.

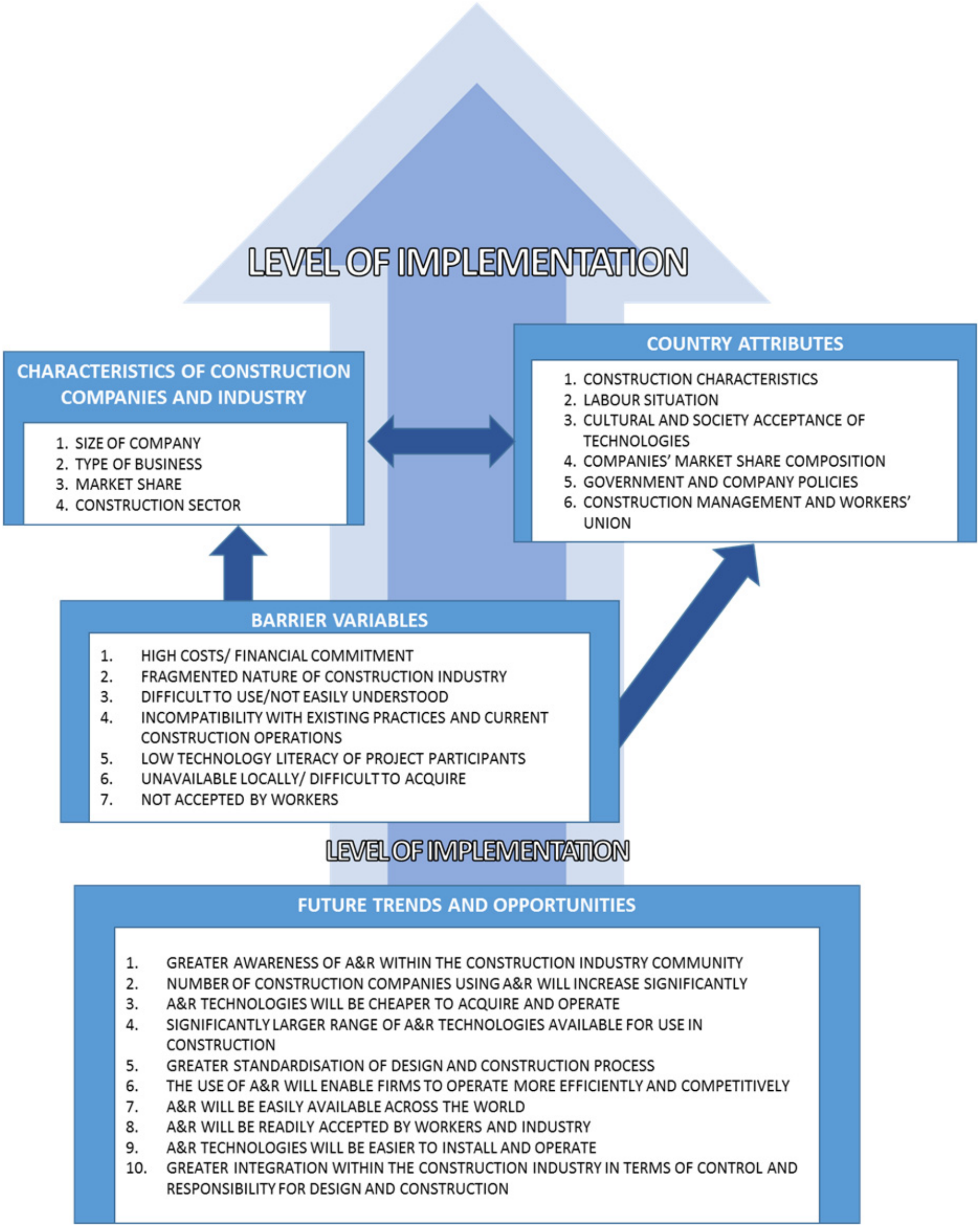

Figure 2: Framework on Construction Automation and Robotics Implementation

References

Balaguer C. and Abderrahim M. (2008). *Trends in Robotics and Automation in Construction, Robotics and Automation in Construction*,, InTech, DOI: 10.5772/5865. On-line: http://www.intechopen.com/books/robotics_and_automation_in_construction/trends_in_robotics_and_automation_in_construction, Accessed: 01/01/2015

Bozyk P. (2006). *Globalisation and the Transformation of Foreign Economic Policy*; Chippenham, Wiltshire, UK: Ashgate Publishing Ltd.

Construction Industry Development Board *Official Website,* http://www.cidb.gov.my, Accessed: 01/01/2015

Construction Research Institute of Malaysia *Official Website* http://www.cream.my, Accessed: 01/01/2015

Hasegawa, Y.(2006). Construction Automation and Robotics in the 21st Century. *Proceedings of the 23rd International Symposium on Automation and Robotics in Construction (ISARC), Tokyo*: 565-568

IAARC (International Association for Automation and Robotics in Construction) *Official Website*, http://www.iaarc.org, Accessed: 01/01/ 2015.

Kajima Corporation (2015), "Official Website"<http://www.kajima.co.jp> Accessed: 01/01/2015

Mahbub, R. (2008). *An Investigation into the Barriers to the Implementation of Automation and Robotics Technologies in the Construction Industry*. Unpublished Thesis, Queensland University of Technology, Australia, 2008. On-line: http://eprints.qut.edu.au/26377/1/Rohana_Mahbub_Thesis.pdf, Accessed: 01/01/2015.

Mahbub, R. (2012). Readiness of a Developing Nation in Implementing Automation and Robotics Technologies in Construction: A Case Study of Malaysia. *Journal of Civil Engineering and Architecture*, *6*(7), 858–866.

Reynolds, S. and Valentine, D. (2004). Guide to Cross-Cultural Communication, Pearson Prentice Hall, USA

Richards L. (2005). *Handling Qualitative Data: A Practical Guide*, UK: Sage Publications.

Richards L. Up and Running in Your Project: A Post-Workshop Handbook for NVivo 7, 2006. On-line: http://download.qsrinternational.com/Document/NVivo7/NVivo7_Up&Running_Lyn_Richards.pdf, Accessed: 01/01/2015

Shimizu Corporation (2015), "Official Website" <http://www.shimz.co.jp> Accessed: 01/01/2015

Takenaka Corporation (2015), "Official Website" http://www.takenaka.co.jp Accessed: 01/01/2015

About Author

Rohana Mahbub is an associate professor at the Faculty of Architecture, Planning and Surveying, Universiti Teknologi MARA, Malaysia and has been lecturing for 27 years. She obtained her PhD from Queensland University of Technology in Built Environment and Engineering in the area of Construction Automation and Robotics; her MSc in Construction Project Management from UMIST and BSc(Hons) in Quantity Surveying from University of Reading. She was the recipient of the Canadian Government Scholarship and Fellowship Programme in 1998 and the Queensland Nippon Foundation grant in 2006; and has also obtained several national grants in her research area. She has published research papers for numerous conferences and academic journals, and her research interests include building automation, construction robotics, industrialised building systems, innovative construction approaches and education in built environment.