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A conceptual framework for selecting construction systems for construction projects delivery

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--***ABSTRACT***--
The choice of appropriate construction systems for construction projects is as important as the success of the construction projects. A systematic selection framework for construction system is needed so as to improve the understanding of construction projects on construction systems and to ensure the achievement of project objectives. This paper proposes a systematic framework for selecting construction system for construction projects. The framework consists of key decision criteria for selecting construction systems and was analyzed using the Analytical Hierarchy Process with consistency ratio of 0.075 [CR<0.10; Lambda = 19.814]. An equation for calculating the expected value for construction projects was formulated. The proposed framework was conceptualized to be based on the expected project value as preferred by the project clients. The framework identifies three major steps to be undertaken towards selecting construction systems for construction projects delivery.The information obtained from the application of the framework would enrich the project design and construction processes. It will also provide information for the development of construction methodology (method statement) for construction projects. The framework is also useful in the training of construction professionals and would improve the construction management practices. This framework is applied by providing two examples.

KEYWORDS: construction systems, construction technology, construction methods, construction projects
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I. INTRODUCTION

New construction technologies are emerging daily and this has an effect on construction methods adopted for construction activities by construction managers. The methods of structuring construction activities and the techniques of utilizing construction technologies are collectively referred to as construction systems. Construction system is essential to the success of construction projects. The appropriateness of construction system for construction project has a significant impact on the success of the construction project. Pan *et al.*(2008) noted that an inappropriate construction system could expose construction projects to undesirable risks.

The success of construction projects is contingent on the objectives of the construction projects. Therefore, the objectives of construction projects should not be determined by the perceptions of the project team members, as it is being done for construction projects. Instead, the objectives of construction projects should be determined by the expected value for the construction projects as indicated by the project objective priorities of the clients. However, the project team members are qualified to select the available and suitable construction technologies within the appropriate construction system.

Using appropriate construction system for construction projects would ensure a trouble-free assessment of project performance and effectiveness of construction methods and technologies. Heuristic-based selection framework for construction system has been developed (Abdul-Kadir *et al*., 2008; Pan *et al*., 2008; Ferrada *et al*., 2013; and Nanyam *et al*., 2015). Abdul-Kadir *et al.* (2008) developed a framework for selecting appropriate conventional and industrialized construction systems for construction projects; Pan *et al.* (2008) developed a decision support matrix for selecting appropriate building system for residential building; Ferrada *et al.* (2013) proposed a knowledge-based model for selecting construction methods; and Nanyam *et al*. (2015) developed a framework for evaluating construction technologies for residential buildings.

The choice of appropriate construction systems for construction projects is as important as the success of the construction projects. A systematic selection framework for construction system is needed so as to improve the understanding of construction projects on construction systems and to ensure the achievement of project objectives. Thus, this paper proposes a systematic framework for selecting construction system for construction projects with a view to reducing the construction projects failure factors.

II. METHODS

A systematic review of the literature was done in order to identify existing construction systems. Keywords such as building system, construction methods, and construction systems were used to search for information. The analysis and classification of construction systems were done using the methods of structuring construction activities and applicable construction technology. Also, from literature, the key decision criteria for selecting construction systems were identified. In order to determine the relative weights of the identified key decision criteria. Sixty- two construction managers with a minimum of 15 years of experience in the construction industry were requested to compare and rate the key decision criteria. Analytical Hierarchy Process was used to determine the relative weights of the decision criteria. At the consistency ratio of 0.075 [CR<0.10; Lambda = 19.814], the results indicate that there is no concern of inconsistency in the pairwise comparison. The proposed framework was conceptualized to be based on the expected project value index as preferred by the project clients. An equation for calculating the expected value for construction projects was formulated and will be used to select the appropriate construction systems in accordance with the recommended *expected value index* for different construction systems.

III. FORMULATION OF FRAMEWORK

3.1 Determining the expected value for the project

The construction system selection process is to be driven by the client's requirements. The client's requirements represent the expected value for the project and should be captured by the construction system selection decision criteria listed in Table 1. The decision criteria for the selection of construction system cover economic viability, work quality, safety, project complexity, productivity, and labour intensity. These six decision criteria will be used to determine the expected value for a construction project based on the client's preferences. The expected value index should then be determined using equation 1.

Table 1: Decision criteria for determining the expected value for construction projects

Criteria	Relative Weight	Priority Value
Economic viability	0.90	Very low priority=10; Low priority=20; Average priority=30; High priority=40; Very high priority=50
Work quality	0.95	Very low priority=10; Low priority=20; Average priority=30; High priority=40; Very high priority=50
Safety	0.85	Very low priority=10; Low priority=20; Average priority=30; High priority=40; Very high priority=50
Project complexity	0.66	Very low priority=10; Low priority=20; Average priority=30; High priority=40; Very high priority=50
Productivity	0.75	Very low priority=10; Low priority=20; Average priority=30; High priority=40; Very high priority=50
Labour intensity	0.71	Very low priority=10; Low priority=20; Average priority=30; High priority=40; Very high priority=50

$Expected\ Value\ Index\ = \sum_{i=1}^{n} W_i P_i$[Equation 1]

Where; $n = number\ of\ decision\ criteria; W = relative\ weight\ of\ the\ ith\ decision\ criteria; P = priority\ value\ indicated\ by\ the\ client\ on\ a\ scale\ of\ 10 - 50$

3.2 Selecting appropriate construction system for the project

Construction system is a concept that has been described using many terms such as building systems, housing systems, and construction methods. There are various construction systems with varying degrees of technologies, activities, methods and benefits. Construction system encompasses the technicality of assembling construction elements to form structures. The various types of construction system represent an improvement in the technologies and methods of carrying out construction activities. Each of these technologies has relative advantages and areas of application depending on the type and requirements of the project. various authors have presented different classification for construction system. Abdul-Kadir *et al*. (2008) classified construction system as the conventional and industrialized building system. Kok (2010) classified construction systems into conventional, cast-in-situ and prefabrication system. Okodi-Iyah (2012) also classified construction systems into conventional, cast-in-situ, prefabrication, and composite system. These classifications are based on technology. Cast-in-situ is a construction technology under the conventional system and therefore cannot be a separate construction system. The industrialized building system is a relaxed term that was adopted to classify non-conventional technologies. The term did not consider the newly emerged technologies. Also, not all non-conventional technologies can be accurately captured as the industrialized system. In addition, prefabrication is a construction technology within industrialized construction system. The classification by Van Gassel *et al.*(2009) attempted to address the shortcomings of the previous classifications. Van Gassel *et al.* (2009) classified construction system into traditional, mechanical, robotised, and automated systems. This classification was systematic in that it analyzed the interrelationships between the resources utilized in the construction systems and the task that the resources are expected to undertake. Construction systems are distinct based on the way of structuring construction activities in each system and the construction technologies that are peculiar to each of the system. Therefore, this paper classified construction systems into Conventional

Construction System, Optimized Conventional Construction System, Machine-aided Construction System, Computer-aided Construction System, Computer Integrated Construction System, and Intelligent Construction System. The proposed classification of the construction systems and the application of construction systems are summarized in Table 2 and Figure 1. Conventional Construction System is a craftmanship-based construction system and characterized by an on-site installation of structural and non-structural components and by use of hand tool. In this type of construction system, labor usage is intensive, production is uncertain, products and processes are flexible, waste generation is high, energy consumption is high, and pollution is high. Also, the construction activities are carried out by workers. Optimized Conventional Construction System is a construction system that was developed to reduce uncertainties in the construction process and reduce the wastage of Conventional Construction System. Optimized Conventional Construction System is characterized by the use of optimized hand tools and optimized construction methods so as to eliminate wastes. Also, physical activities are carried out by workers with improved tools and decisions are made also by workers but with mathematical, conceptual or algorithmic-based decision support model.

Machine-aided Construction System is an industrialized system of construction. It mechanizes the construction process by expanding the limits of craftsmen with machines. Machine-aided Construction System is characterized by the use of construction plants and equipment, prefabrication and precast, use of manufactured components, preassembly, advanced formwork technology, concrete masonry technology, and standardization. In this system, physical activities are done by workers with the aid of machines. Computer-aided Construction System is a construction system that makes use of programmable machines and equipment. It automates the construction process through the combination of computers with machines so as to expand the limits of machines. Arayici *et al.* (2006) described the Computer Integrated Construction System as a collaborative system of construction in computer environments. Bjork (1994) observed that Computer Integrated Construction System is characterized by extensive utilization of computer software applications and extensive flow of digital information. this system utilizes advanced information technology in construction by expanding the automation of machines and making use of object-oriented application software. Also, it makes use of machines integrated with computers and microprocessors. Intelligent Construction System is an intelligence-based construction system that is characterized by the use of artificial intelligence in planning, intelligent construction robots and other computational devices such as sensors, programmable controllers, onboard microprocessors, central computer, fibre-optic gyroscope, laser, colour image processor, manipulators, end effectors, electronic controls, motion systems, and numerical control. Although, each of these construction systems has its advantages and disadvantages depending on the projects' objectives. However, successive construction systems represent an improvement over the preceding ones.

The expected value for the project as discussed in the last section will be used to select the appropriate construction system for the construction project based on the recommendation level for construction system as contained in Table 3. The recommended level for construction system was designed to reflect the benefits to be derived from the construction system. As the benefits of the construction system increases, the expected value for project increases. The least project value is expected from conventional construction system; while the intelligent construction system gives the highest value for construction projects.

Table 2: Classification of construction systems

Construction system	Physical activities	Cognitive activities	Decision-making activities
Conventional Construction System	Workers and tools	Workers	Workers
Optimized Conventional Construction System	Workers and improved tools	Workers	Workers and decision support tools
Machine-aided Construction System	Workers and machine	Workers	Workers and computer software
Computer-aided Construction System	Automated machine	Workers and 2D application software	Workers and 2D application software
Computer Integrated Construction System	Construction robots	3D application software	Workers and 3D application software
Intelligent Construction System	Intelligent construction robots	Cognitive devices	Artificial intelligence

	TECHNIQUES	OBJECTIVES	APPLICATIONS
CONVENTIONAL CONSTRUCTION SYSTEM	**Empirical methods, skilled labour, construction tools**	**Simple planning, basic construction operations**	**basic construction operations, unsophisticated construction projects**
OPTIMIZED CONVENTIONAL CONSTRUCTION SYSTEM	**Mathematical models, algorithmic approach, conceptual models, Information Technologies**	**Efficient labour, waste and delay reduction**	**Tedious construction operations**
MACHINE-AIDED CONSTRUCTION SYSTEM	**Precast ad prefabrication (mass production/manufacturing),**	**Productivity and quality, worker shortage problems**	**Labour-intensive construction operations**

	partial mechanization, standardization		
COMPUTER-AIDED CONSTRUCTION SYSTEM	**Partial automation, total mechanization, remote control**	**Time/cost/labour saving, safety and quality works**	**High skill and heavy construction operations**
COMPUTER INTEGRATED CONSTRUCTION SYSTEM	**Total automation, construction robots**	**Improved productivity and quality, efficient usage and control of construction machines and equipment**	**Dangerous and hazardous construction operations**
INTELLIGENT CONSTRUCTION SYSTEM	**Cognitive construction robots, advanced information technologies, artificial intelligence**	**Higher productivity and quality, cost and time reduction, improved control and efficiency of construction machines**	**Construction operations requiring precision and intelligence, hazardous and inaccessible construction environment**

Figure 1: Techniques, objectives and application of construction systems

Table 3: Recommended project value for various construction systems

Expected Value Index	Recommended Construction Systems
≤ 36	Conventional Construction System
37 - 77	Optimized Conventional Construction System
78 - 118	Machine-aided Construction System
119 - 159	Computer-aided Construction System
160 - 200	Computer Integrated Construction System
≥ 201	Intelligent Construction System

3.3 Deciding on technologies of construction methods

Following the selection of the appropriate construction system, the next step is to decide on available technologies of construction methods. Within the selected construction systems, the next stage is to decide on the available technologies for (a) project planning, (b) construction materials, (c) installation and assembly, (d) material handling, (e) information management. A summary of the available technologies within the construction systems is presented in Table 4 – Table 9.The structure of the construction activities should also be planned by developing a work breaking structure and manpower plan. The type of manpower to be used for construction projects should be informed by the type of construction activities and the type of construction system.

Table 4: Construction methods for the conventional construction system

Construction methods for the conventional construction system
Division of labour
Fibreglass/steel/timber
Masonry construction(brick/stone)
Hand excavation
Cast-in-situ concrete technologies
Manual erection and assembly
Reinforced concrete frames
Skilled labour operation
Construction tools
Conventional building materials
Gang-sizing and target outputs
Falsework and scaffolding
Cross-wall construction

Table 5: Construction methods for the optimized conventional construction system

Construction methods for the optimized conventional construction system
Hill-climbing algorithm
Euclid's algorithm (flowchart)
Critical path analysis/PERT
Compression analysis
Last planner technique
Line of balance
Genetic algorithm
Ant colony algorithm
Particle swarm algorithm
Hybrid evolutionary algorithm
Whale optimization algorithm
A* algorithm
Best-first algorithm

Steepest-ascent algorithm
Hill climbing algorithm
Multiple activity charts
Game theory
Waiting line theory
Fuzzy set theory
Linear programming
Dynamic programming
Integer programming
Just-in-time principle
Function analysis
Constructability principles
Lean construction principles
Sustainability principles
Siemens approximation
Fondahl's approach
2D/3D CAD software technologies
Virtual/mock-up construction
Work study

Table 6: Construction methods for the machine-aided construction system

Construction methods for the machine-aided construction system	
Draglines	Loader cranes
Backactor	Pile-driving equipment
Dozers	Water-pumping machine
Clamshells/grabs	Gravel crusher
Graders and levellers	Concrete block making the machine
Tractor shovels	Sand making machine
Hydraulic excavator	Sand washing machine
Scrapers	Concrete mixer
Face shovels	Concrete pumps
Trenching machine	Concrete placer
Skimmers	Concrete mixer trucks
Tamping machines and road rollers	Concrete cutter
Micro-tunnelling machine	Plastering machine
Dump trucks/ dumpers	Concrete lining paver
Hoist platform and cages	Concrete vibrators
Loaders	Shotcrete machine
Lifts and escalators	Wood and steel processing machine
Tipper lorries	Bituminous distributor
Forklift trucks	Road surfacing units
Derricks	Road planners and heaters
Chutes	Road rollers
Vans	Chipping spreaders
Belt conveyors	Asphalt and bituminous mixing plant
Chute conveyor	Spreading and finishing machine
Chain conveyor	Bitumen heaters
Bucket conveyor	Mixer plants
Trolley conveyor	Truck mixers
Lift trucks	Concrete surface vibrator
Tower cranes	Soil stabilizing machine
Crawler cranes	Infrared heaters
Vehicle cranes	Core boring machines
Floating cranes	Asphalt tarmacadam machines
Floating cranes	Concrete scrapper
Overhead cranes	Terrazzo grinding machine
Side-lift cranes	Sandblasting machine
Jib cranes	Cleaners
Asphalt road cutter	Road rollers
Asphalt recyclers	Sheep foot rollers
Road cleaning machine	Prefabrication and precast
Road kerbing machine	Manufactured components
Pothole patcher machine	Preassembly
Paver finisher	Advanced formwork technology
Bitumen Sprayer	Concrete masonry technology
Chip spreader	Standardization

Table 7: Construction methods for the computer-aided construction system

Construction methods for the computer-aided construction system
Automated cranes
Automated conveyor systems
Automated elevator systems
Autonomous dump trucks
Automatically guided vehicles
Automated 3D lasers canning

Automated road kerb machine
Unmanned aerial vehicles (UAVs)
Light detection and ranging
Automated construction sites
Automatic levels
Autonomous excavator
Automatic laser receiver
Automated batching plant
Automated rebar placing vehicles
Automated stone-cutting machine
Automated sort-grading machines
Automatic sensor
Automatic slip-form machines
Push- Up
Big canopy
Bar coding technology
Remotely controlled machines
Automated pipe construction machines
Automated concrete distribution machine
Totally mechanized construction system
Computer Assisted manoeuvring
Automated mortar-spreading and brick-laying machines
High-tech mechanical devices
Tele-operated micro-tunnelling machines
Automated Building Construction System
Mast Climbing Construction System
AKWTSUKI 21

Table 8: Construction methods for computer integrated construction system

Construction methods for computer integrated construction system
Robotic total station
Mighty hand ribo
Structural welding robot
Fireproofing spray robot
Screeding/tile-setting robot
Wall inspection robot
Floor-levelling robot
Walls and ceiling painting robot
Computer Numerical Control concrete placement machine
Tile inspection robot
Pipe inspection robot
Robot excavator
Pile-driving robot
Shotcrete robot
Slab-finishing robot
Steel-erection robot
Block-laying robot
Walls and ceilings plastering robot
Rebar fixing robot
Bridge inspection robot
Shimizu's manufacturing with advanced robotic technology (SMART) system

Table 9: Construction methods for the intelligent construction system

Construction methods for the intelligent construction system
Distributed AI-controlled robots
BIM-based construction technology
VR &AR-based construction technology
3D-printing technology/ Digital fabrication
Drone-based construction technology
GPS based construction technology
Sensing technology-based construction

IV. EXAMPLE OF APPLICATION

4.1 Example 1

A proposed one block of 2 – storey high administrative building with a building area of 175.22 m^2 and four staircases. The floor spaces in the building as planned include ground floor spaces (cafeteria, kitchen, archive room, lobby, electricity room, maintenance room, reception hall, WC, and speaker room), first floor spaces (directors' office, general manager's office, regional manager's office, sales office, archive room, boardroom, HR manager's office, distributors' office, fire and safety room, and secretary's office), and second floor spaces (waiting room, equipment room, boardroom, archive room, MD office, estate manager's office, builder's office, architect's office, quantity surveyor's office, planner's office, fire and safety room, and secretary's office). Select an appropriate construction system and plan the utilization of construction technologies for the project.

Solution:

Step 1: Determining the expected value of the project

Criteria	Relative Weight	Priority Value	Expected Value
Economic viability	0.90	High priority = 40	36
Work quality	0.95	High priority = 40	38
Safety	0.85	Low priority = 20	17
Project complexity	0.66	Very low priority = 10	6.6
Productivity	0.75	Average priority = 30	22.5
Labor intensity	0.71	Very low priority = 10	7.1
$\sum \cong$ ***128***			

Step 2 & 3: Selecting the appropriate construction system for the project and deciding on technologies of construction methods.

Construction System	Construction Methods	Selected Technologies
@ project value of 128, the recommended construction system is Computer-aided Construction System	Project planning	2D CAD
	Construction materials	Manufactured components
	Installation and assembly	Selection of appropriate machines from Table 7
	Material handling	Selection of appropriate machines from Table 7
	Information management	An automated information management system

4.2 Example 2

Select an appropriate construction system and plan the utilization of construction technologies for the project for a proposed one block of 8-storey high residential flat with five residential units per storey.

Solution:

Step 1: Determining the expected value of the project

Criteria	Relative Weight	Priority Value	Expected Value
Economic viability	0.90	Average priority = 30	27
Work quality	0.95	Average priority = 30	28.5
Safety	0.85	Low priority = 20	17
Project complexity	0.66	Very low priority = 10	6.6
Productivity	0.75	Average priority = 30	22.5
Labor intensity	0.71	Very low priority = 10	7.1
$\sum \cong$ ***109***			

Step 2 & 3: Selecting the appropriate construction system for the project and deciding on technologies of construction methods.

Construction System	Construction Methods	Selected Technologies
@ project value of 109, the recommended construction system is Machine-aided Construction System	Project planning	Software technologies
	Construction materials	Prefabricated and precast materials; Manufactured components
	Installation and assembly	Selection of appropriate machines from Table 6
	Material handling	Selection of appropriate machines from Table 6
	Information management	Manual/computer-based information management system

V. CONCLUSION

This paper develops a conceptual framework for selecting construction systems for construction projects delivery. This is significant given the availability of various construction technologies and the emerging ones. The framework identifies three major steps to be undertaken towards selecting construction systems for construction projects delivery. In the framework, construction technologies were categorized into six groups, namely Conventional Construction System, Optimized Conventional Construction System, Machine-aided Construction System, Computer-aided Construction System, Computer Integrated Construction System, and Intelligent Construction System. The framework also identifies six criteria for selecting the appropriate construction system for construction projects. these criteria include Economic viability, Work quality, Safety, Project complexity, Productivity, and Labour intensity. The selection of the appropriate construction system for construction projects will also determine the decision on the construction technologies to be adopted for the construction projects. The construction technologies constitute the construction method for the project; while the various sections of the construction method as conceptualized by the framework include Project planning, Construction materials, Installation and assembly, Material handling, and Information management.

Furthermore, the paper provides two examples of applying the framework. The significance of the framework is in the decision-making process for project viability and conceptual planning and structures the usage of various construction technologies. Also, the framework provides the differences and relationships between construction systems, construction technologies, and construction technologies. The framework is applicable to all types of construction projects. the results obtained from the application of the framework would enrich the project design and construction processes. It will also provide information for the development of construction methodology (method statement)for construction projects. The framework is also useful in the training of construction professionals and would improve the construction management practices.

REFERENCES

[1]. Abdulkadir, M.R., Lee, W.P., Jaafar, M.S., Sapuan, S.M. & Ali, A.A.A. (2006). Construction performance comparison between conventional and industrialised building systems in Malaysia. *Structural Survey* [online]. 24 (5):412-424. [Accessed 10 December 2011]. Available at www.emeraldinsight.com/0263-080X.htm.

[2]. Arayici, Y., Ahmed, V., and Aouad, G. (2006). A requirements engineering framework for integrated systems development for the construction industry. ITCON, 11: 35 – 56.

[3]. Bjork, B. C. (1994). The RATAS project – developing an infrastructure for computer integrated construction. Journal of Computing in Civil Engineering, 8(4): 401-419.

[4]. Ferreda, X., Serpell, A., and Skibniewski, M. (2013). Selection of construction methods: A knowledge-based approach. The Scientific World Journal. DOI: 10.1155/2013/938503.

[5]. Kok, T. S. (2010). *Cost-effectiveness comparison of pre-fabrication with conventional construction method for RMAF ground defense bunker*. M. Sc. Thesis. UniversitiTeknologi Malaysia [online]. [Accessed 10 December 2011]. Available at http://eprints.utm.my/10636/.

[6]. Nanyam, N., Basu, R., Sawhney, A., and Prasad, J. K. (2015). Selection framework for evaluating housing technologies. Procedia Engineering, Elsevier, 123: 333 – 341.

[7]. Okodi-Iyah, E. Y. (2012). A comparative evaluation of the environmental impact of prefabrication versus conventional construction in UAE's construction industry. MSc. Dissertation, Faculty of Engineering and Information Technology, the British University in Dubai.

[8]. Pan, W., Gibb, A. G. F., and Dainty, A. R. J. (2008). A decision support matrix for build system selection in housing construction. International Journal for Housing Science and its Application, 32(1): 61-79.

[9]. References.

[10]. vanGassel, F. J., Maas, G. J., & Van Bronswijk, J. E. M. H. (2009). A Research Model for Architectural Meetings to Support the Implementation of New Building Technologies through Collaboration of Brainpower. In 26th International Symposium on Automation and Robotics in Construction (ISARC 2009), Austin, TX, USA.

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