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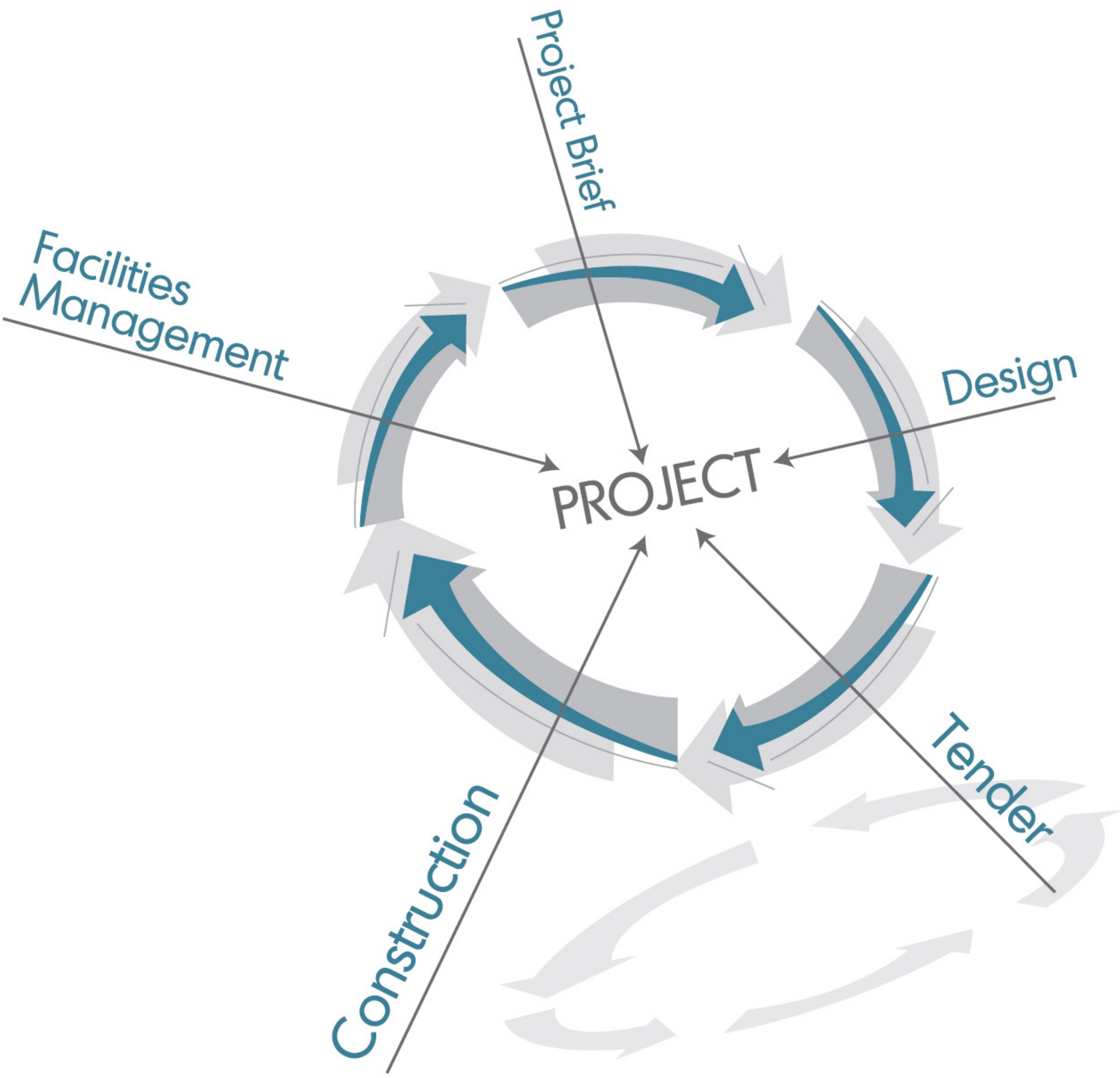

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Construction Research Institute of Malaysia (CREAM)
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No. 100, Jalan Putra,
50350 Kuala Lumpur
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Contents

Editorial Advisory Board

Editorial

Welcome from the Editors

Welcome to the twenty-fifth (25^{th}) issue of Malaysian Construction Research Journal (MCRJ). In this issue, we are pleased to include eight papers that cover wide range of research area in construction industry. The editorial team would like to express our sincere gratitude to all contributing authors and reviewers for their contributions, continuous support and comments.

In this issue:

As sustainability has become a vital element in building development, **Muhammad Syukri Imran et al.,** investigated the applicability of hydronic radiant cooling system charged with night cooled water in combination with Earth Tube Heat Exchanger (ETHE) to cool down a residential building in Malaysia. The hybrid system is found to meet the thermal comfort that building occupants desire and improve the indoor operative temperature by using natural heat sink sources such as the night sky and cooler ground. This allows the hybrid system to save 95% energy, as shown in a simulation. The results of the study are further explained in this paper.

Considering the limitation of architectural design theory for high-rise buildings in a topical country like Malaysia, **Foo Chee Hung et al.,** proposed a flexible housing design system for the high-rise affordable housing which is a combined design and construction system that makes use of an open plan design concept and the Industrialised Building System (IBS) construction method. The proposed design can facilitate the shift towards higher quality, affordable and sustainable housing in Malaysia. Other advantages of the proposed design are also discussed in this paper.

Juliana Brahim et al., reviewed the current practices of building information modelling (BIM) in Design and Build (D&B) projects in the Malaysian construction industry. A semi-structured interview is conducted with construction players that are currently involved and have experiences in the projects. The findings, which are discussed in this paper, revealed that the construction players are still unable to make the most of BIM benefits.

Natasha Khalil and Syahrul Nizam Kamaruzzaman explored the impact of building performance failure to the occupant's health and safety risks, in accordance with the performance elements and criteria.

Nor Hayati Abdul Hamid et al., evaluated the seismic performance of double bay two-storey reinforced concrete (RC) frame under in-plane lateral cyclic loading. The parameters for this study are the in-plane lateral cyclic loadings range from ±0.2% to ±3.0% drift with an increment of ±0.25%. A one-half scale prototype model of RC moment resisting frame used for testing was constructed in heavy structural laboratory for this study. The results are discussed in this paper.

Tengku Anita Raja Hussin et al., conducted a study to determine the strength of the glued-in steel dowel for Kempas species by testing it with different thickness and the types of failure modes were then observed. The glued-in steel dowel is 10mm in diameter and the results showed that for such diameter, 3mm is the optimum glueline thickness.

Marco Caiza et al., determined the physical properties and the effects of volcanic pumice from north-central Ecuador when used as a coarse aggregate for lightweight concrete. The results are then compared with concrete manufactured with conventional coarse aggregate. The findings show that as the pumice has a low density compared to the conventional aggregate, it may be used as a coarse aggregate for lightweight concrete. The pumice also demonstrates a higher absorption than the conventional aggregate as it is a porous material. The findings are further discussed in this paper.

Ahmad Ruslan Mohd Ridzuan et al., study the strength characteristic and the chloride permeability level of self-consolidating concrete (SCC) containing a mixed of recycled concrete aggregate (RCA), whose content ranges from 0% to 100% of natural aggregate, and waste paper sludge ash (WPSA) at optimum levels. The parameter of this study is the RCA content. The findings are then compared with SCC containing normal mixes and it was indicated that the compressive strength and chloride permeability of SCC containing 100% RCA replacement shows a comparable performance with that of SCC containing normal mixes.

Editorial Committee

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BIOCLIMATIC HOME COOLING DESIGN FOR ACCEPTABLE THERMAL COMFORT IN MALAYSIAN CLIMATE

Muhammad Syukri Imran, Azhaili Baharun, Siti Halipah Ibrahim, and Wan Azlan Wan Zainal Abidin
Engineering Faculty, University Malaysia Sarawak, 94300 Kota Samarahan, Sarawak, Malaysia.

Abstract
This study investigates the applicability of hydronic radiant cooling system charged with night cooled water in combination with Earth Tube Heat Exchanger (ETHE) to cool down a residential building in Malaysia. Through the use of building simulation program, it is possible to design an environmentally friendly or bioclimatic building where sustainability has become a crucial element in building development. The hybrid system takes advantage of the readily available heat sink source such as the night sky and cooler ground to passively cool down a residential building. The annual simulation using Energy Plus program shows that 95% of the time the building occupant could expect an indoor operative temperature of not more than 28.5 ºC. The hybrid system can meet the thermal comfort standard set by ASHRAE Standard 55 and ISO 7730. The hybrid system is also able to improve the base case operative temperature of 33.5ºC to 28.5ºC. Simulation on energy spent shows that as much as 95% energy can be saved by using the hybrid system. This level of saving is not impossible as the renewable night cooled chill water is used to charge the indoor radiant cooling system in place of an energy-guzzling air conditioning compressors.

Keywords: *Bioclimatic Building; Energy Plus; earth tube heat exchanger; hydronic radiator; night cooled water*

INTRODUCTION

In the modern world society, sustainability has become a crucial element in building development. Thus, it has become necessary for building designer or developers to design a building according to bioclimatic principles. Balance in the relationship between the home occupants, the housing and climate defines the sustainability that is required for a bioclimatic housing. Some input measures in the bioclimatic housing include the use of passive systems rather than active mechanical systems, renewable energy systems, sustainable materials, water as well as the integration of passive system through integration of microclimate and active system (Hyde, 2008). The given measures normally are aimed to improve the comfort and well-being of occupants, reduce environmental impact as well as reduction of cost over life cycle period. In the past ventilation, dehumidification and shading have been seen as integral to the passive design of building in Malaysia (Zain et al., 1998). Over time the sustainability has demanded more from building design and requires building to embrace and respond to the local environment as oppose to challenging the environment with mechanical systems. The focus is now given in resource conservation and applying new technology to help buildings to be more climate adaptive or responsive to the natural condition. This technique to use new technology to enhance or amplify bioclimatic strategy have become the latest trend in architecture as humans are required to adapt to a rapidly warming world (Gregor, 2014).

Air conditioning is seen as a part of the climate change problem as the energy used to run the systems contributes to greenhouse emissions therefore give rise to adoption of more effective methods of passively cooling buildings. The cooling method or system required not only need to function as part of the warming world solution but also have to meet the human and environmental need. Building developers nowadays construct residential homes with little regards to indoor thermal comfort thus forcing the future owner of building to install a mechanical means of cooling the indoor environment. The mechanical cooling only serves as a bandage to a poor building design. The indoor temperature may be somewhere between 34°C to 36 °C in the afternoon which is beyond the thermal comfort range set by ASHRAE Standard 55 (ANSI/ASHRAE, 2013) and ISO 7730 (ISO, 2005). Investigation by other local researcher such as Ibrahim and Tinker (2005); Rajeh (1994); Nugroho (2011); Kamar et al. (2012); Azhaili et al. (2011) as well as Normah et al. (2012) have showed that typical Malaysian residential house including low-income house failed to provide the minimum thermal comfort target. There exists an opportunity to integrate the passive and active system to improve thermal comfort as well as to gain benefits of reduced energy consumption. This study investigates the use of passive and active system to provide cooling according to site condition in Malaysia which could meet indoor thermal comfort as well as energy conservation.

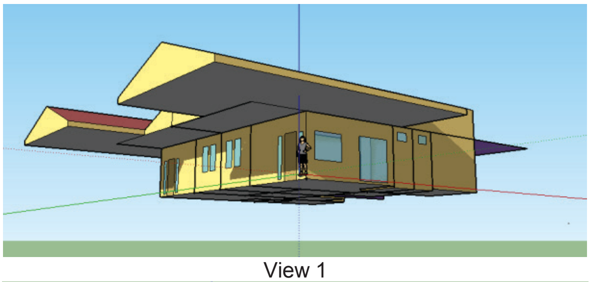
The objective of this study is to find out the thermal comfort and energy savings performance of building model fitted with hydronic radiator device charged with renewable night cooled water in combination with Earth Tube Heat Exchanger (ETHE). The application of this hybrid system for housing has never been tested in Malaysian climatic condition. However, the potential of both the night cooled system and ETHE have been studied independently and separately by other researchers [(Sanusi et al., 2013); (Sanusi et al., 2014); (Imran et al., 2017); (Imran et al., 2016a); (Imran et al., 2016b); (Imran et al., 2016c)]. The system utilizes the night sky and cool ground as heat sink source to cool a residential building. A component such as hydronic indoor radiant panel or heat absorber and earth tube is used as a heat exchanger in two different ways to link the building to the natural heat sink source. The hydronic radiant panel uses chill water as its cooling medium to cool the indoor building surfaces. The radiant surface will cool the surrounding surfaces and the occupants through radiant heat exchange. The chill water is obtained from a night cooling process where the water is cooled down by radiation and evaporation to the cool night sky. The method utilizes the building roof as another readily available heat exchanger to cool the water at night. The cooled water is stored in the water tank and is used during the daytime to charge the indoor hydronic radiant panel. The ETHE function is to precool the ventilation air by forcing the warm outdoor ventilation air through underground pipe before delivering the precooled air to the building. The study gives focus on the use of the night sky cooled water and the ground as a bioclimatic approach in cooling down residential building in Malaysia. Computer aided building simulation is used in the study to show the interaction between occupants, building, the cooling systems and the outdoor climate. The simulation results could be used as a guide and basis to experiment the system in the real world.

METHODOLOGY

Building simulation program using Energy Plus (EP) v8.1

Through the use of building simulation program it is possible to design an environmentally friendly building. Building simulation programs have currently become a growing trend towards environmental protection and achieving sustainable development (Hong et al., 2000). EP is used in this study to test out a new design which involves the combination of a hydronic radiator panel and a earth tube heat exchanger to provide an alternative method to cool a building. The use of EP allows the calculation of building heat gains and to determine the peak load and cooling load profiles. The program is also capable of predicting the building energy consumption as well as the human thermal comfort condition given the building construction detail and other detail such as internal loads such as people, lighting and equipment. The program also allows the technical and economic evaluation of some innovative strategies for energy saving and passive design options. EP is an open source code building energy simulation computer program which has its root from 1970s predecessor BLAST and DOE-2 program that has been reengineered significantly by developers so that the program is current and up to date with technological advances (Department of Energy, 2013). EP has no user interface feature as it was intended to be a simulation engine where the user will input the description of the building such as the physical makeup and associated mechanical system before EP calculate the cooling or heating load, energy consumption as well as many other simulation details. To improve its functionality, in 2008 National Renewable Energy Lab (NREL) have developed Open Studio Application Suite a free interface to run EP that is also a collection of software tools which provide graphical interface including a plug-in or extension to work with SketchUp 3D drawing program. The plug-in permits users to create building geometry easily, to view EP input file in 3D, carry out EP simulation as well as to view the result without leaving SketchUp. EP is chosen to as its capabilities are sufficient for the scope of the study and can be downloaded for free from its home website. The program is validated to evaluate its accuracy and is presented here.

By using SkectchUp and Open Studio Suites, a single storey residential building is created with certain boundary condition as shown in Figure 1.



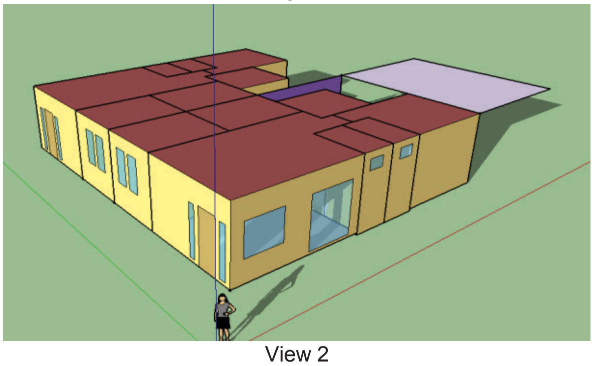


Figure 1. Building geometry constructed in SketchUp

The building model is a typical building type found in Malaysia. Weather data for Malaysian region can be obtained from EP download site. Table 1 shows the building category that is being studied and a list of output obtained from the simulation run.

Table 1. List of simulation output

Building category		Simulation output
Semi Detached house	a.	Area of radiant cooling surface
	b.	Cooling energy
	c.	Cooling load
	d.	Indoor mean air temperature
	e.	Indoor mean radiant temperature
	f.	PMV output for thermal comfort assessment
	g.	Annual operative temperature
	h.	Tank water temperature
	i.	ETHE tube length
	j.	Pump sizing
	k.	Fan sizing

For the purpose of the base case model simulation, the building thermal properties are set to a minimum requirement as per building energy standard of Malaysia (Standard Malaysia, 2007). The radiant and the ETHE system are tested in multiple different configurations. An example of system configuration of the radiant system and ETHE installation is shown in Table 2 and Table 3 respectively. System configuration for ETHE is selected according to a local ETHE study by Imran et al. (2017).

Table 2. System configuration for radiant system in the building model

Design Parameter	Input
System Type as per ISO 11855-2	Type A
No of Thermal Zone	15
Surface Name or Radiant Surface Group Name	Ceiling and wall
Hydronic Tubing Inside Diameter (m)	0.012
Hydronic Tubing Spacing (m)	0.154
Temperature Control Type	Operative temperature
Chill water tank volume per unit home (m^3)	12.5

Table 3. System configuration of ETHE installation in the building model

Design Parameter	Units	Input
Earth tube type	-	Exhaust
Pipe Material	-	Clay/ concrete pipe
Pipe Radius	m	0.04
Pipe Thickness	m	0.003
Pipe Length	m	150
Pipe Thermal Conductivity	W/m.K	1.8
Pipe Depth Under Ground Surface	m	1.5
Design Flowrate	m^3/s	0.4
Avg Soil Surface Temp	°C	28

Computer programme: Validation against field data set

Discussion from an energy modeling community question and answers website show that field data to validate EP model is currently not abundant. According to Hong et al. (2014), empirical test for EP is still a growing area. However, through US Department of Environment funding the Lawrence Berkeley National Laboratory (LBNL) is currently working to build flexible testbed facilities or Facility for Low Energy Experiments in

Buildings (FLEXLAB). The FLEXLAB is primarily used to extract useful field performance data of a wide range of building component such as lighting, controls, windows, façade and other building systems such as Heating Ventilation Air Conditioning (HVAC). Data collection from FLEXLAB may also be used to validate result predicted by EP while complying with Annex 58 quality procedures for dynamic full-scale testing. Annex 58 is an ongoing project run by International Energy Agency (IEA) under Energy in Building and Community program that develops the necessary tools, knowledge, and networks to achieve high quality in situ dynamic testing and data analysis method. Validation of EP with FLEXLAB and Annex 58 is still in early stage and yet to have any software validation report. Therefore, a validation exercise of EP is carried out in this study for increased confidence.

The following describes the independent validation process of EP. Figure 2 shows a single storey semi detached house located in Kuching, Sarawak which was selected to be modeled in EP.

Figure 2. Single storey semi detached house in Kuching Sarawak

The objective of the validation work is to compare the results predicted by the EP with empirical data obtained from the building site. In this case, the Operative Temperature (OT) of the building is the parameter or the subject of comparison. The construction of the building uses the typical material for construction such as brick wall, concrete tile roofing with a light insulation layer, concrete slab, glass window and timber door.

Details of the building geometry, construction type with its thermophysical properties and building thermal load were obtained from site survey work as well as building energy standards such as Malaysian Standard 1525 and Chartered Institution of Building Services Engineers (CIBSE) design guide (CIBSE, 2006). The building geometry was first created in a drawing program; Sketch Up as an open studio model and is saved as a .osm file extension. The model is then loaded to Open Studio Application Suite; a free interface to run EP, where amendments can be done on the construction material thermophysical properties, thermal loads including its schedules where necessary according to the required detail. The simulation is carried out for the local climatic region. Therefore, the climatic information such as site wind speed, wind direction, site diffused, and direct solar radiation rate, relative humidity and dry bulb temperature have to be corrected to reflect the actual weather condition during which the site measurement was conducted. To complete the validation exercise, on-site measurement was conducted between 11th and 13th October 2015. The hourly internal surface temperatures of all six surfaces in a selected room were recorded with a temperature data logger including the room air temperature and humidity level. At the same time measurement were also taken for the climatic condition such outdoor mean air temperature, outdoor air relative humidity, solar radiation rate as well as the outdoor wind speed. Other climatic info was also obtained from the local airport weather station. The on-site measurement data is used to determine the operative temperature of the selected room and is compared to predicted result from EP. Given the uncertainty in the thermos physical properties of building construction material, several simulations were done for a range of thermophysical value which gives a range of predicted room operative temperatures. A mean operative temperature value is then established from this multi-simulation run. Figure 3 shows that the in-situ measurement closely compares to the mean value predicted by EP with a maximum error of 3.2% or ± 0.3ºC.

Apart from the validation of EP result, calibration of the ETHE before the simulation run is also carried out by comparing the simulated temperature of the air entering the thermal zone after passing through the earth tube with an actual experiment conducted by another study by Sanusi et al. (2013). The ground interface temperature is set to 28°C based on the finding of the same study. Calibration result is shown in Table 4. The first step in the simulation was to determine the indoor thermal comfort condition of the base case building. The simulation was then repeated to find out the thermal comfort condition of the same building fitted with radiant cooling surfaces as well as the ETHE. The result is then presented in term of indoor operative temperature as well as PMV index for a design day and annual simulation run. The energy consumption of the base case building and the retrofitted building is also evaluated.

Table 4. Calibration of simulation model with an actual earth tube experiment by Sanusi et al. (2013)

Calibrated parameter	Simulation Model	Value by Sanusi et al. (2013)	Error
Outdoor Air DBT Peak Temperature °C	33.8	34.1	0.9%
Earth Tube Zone Inlet Air Temperature °C*	28.1	28.0	0.4%

*Earth Tube Zone Inlet Air Temperature refers to the temperature of the air entering the zone after passing through the earth tube [C].

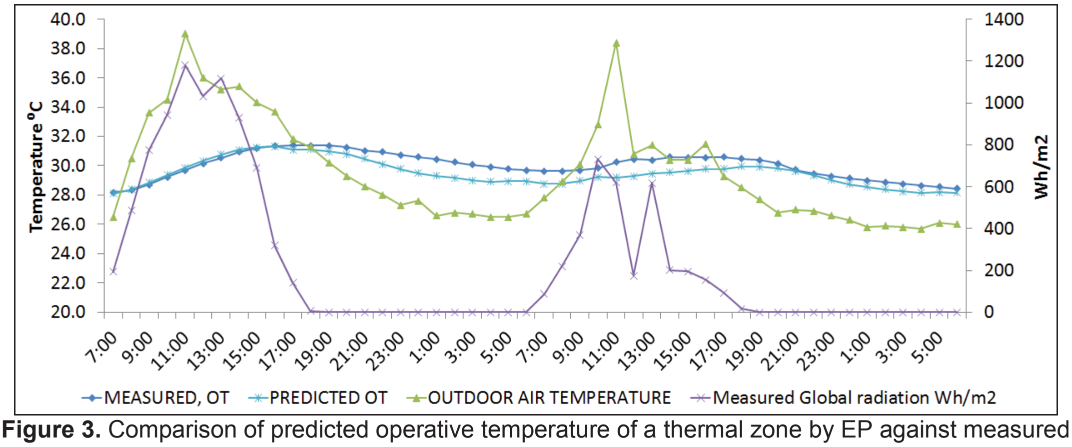


Figure 3. Comparison of predicted operative temperature of a thermal zone by EP against measured data on site

RESULT

Annual simulation is conducted for the building model with the radiant system only as a stand-alone system and the result of the simulation is shown in Figure 4. The annual operative temperature for a thermal zone of the building model is improved to 28ºC or over 80% of the time. The thermal condition is within the acceptable range of 21ºC to 28ºC for condition spaces as specified by ASHRAE (ANSI/ASHRAE, 2013) with an air velocity of up to 0.2m/s. ASHRAE has specified that the upper limit could be increased to 31ºC if the occupant control air velocity is elevated to 1.2 m/s. The average comfort zone upper limit in Malaysia is found to be 30.1ºC (Aliyah, 2012). Therefore, the radiant system is capable of meeting both ASHRAE and Malaysian comfort zone upper limit. In term of heat balance, the radiant system which is charged with night cooled water of 24ºC has resulted in lower indoor ceiling and wall surface temperature. Radiation heat exchange takes place between the cool surfaces and short-wave radiation of lights, transmitted solar as well as long wave radiation with other internal surfaces. Apart from the radiation heat exchange, convention heat exchange also takes place between the cool surface and the indoor zone air. The low zone surface temperature as well as the air temperature have resulted in a lower and acceptable operative temperature of generally between 28ºC and 29.5ºC.

Figure 5 presents the annual operative temperature for the same building model with earth tube system only present to provide indoor cooling. The earth tube system is designed to precool ventilation air before entering the zone thus providing a cooler air temperature. However, the precooled air is not sufficient to cool the zone indoor air through convective cooling. The operative temperature of the building model is improved slightly however still not able to meet the thermal comfort zone upper limit of 30.1ºC.

Room air temperature and mean radiant temperature are two parameters that have the same influence on thermal comfort (ISO, 2005). The water based (hydronic radiator) and air-based system (ETHE) introduced in this study are meant to improve both of these parameters. The average of these two values is expressed as the operative temperature. Operative temperature is usually used as an indicator of indoor thermal comfort condition (Tang & Chin, 2013). The water based and air-based system is combined to become a hybrid system in the simulation run to see how it will impact the indoor thermal comfort of the building model. Figure 6 presents the annual operative temperature provided by the hybrid system found in the building model.

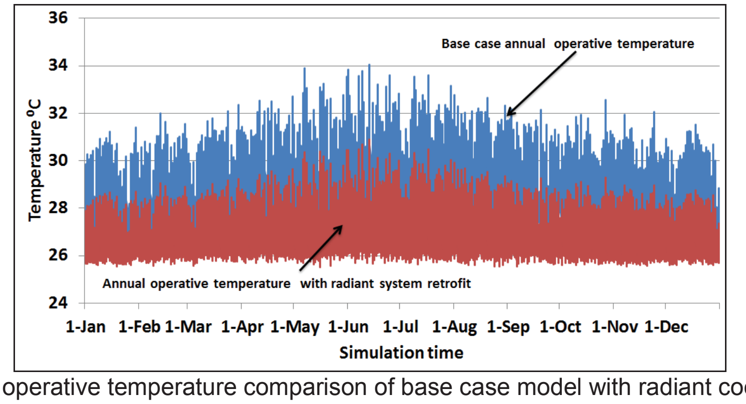


Figure 4. Annual operative temperature comparison of base case model with radiant cooling system only

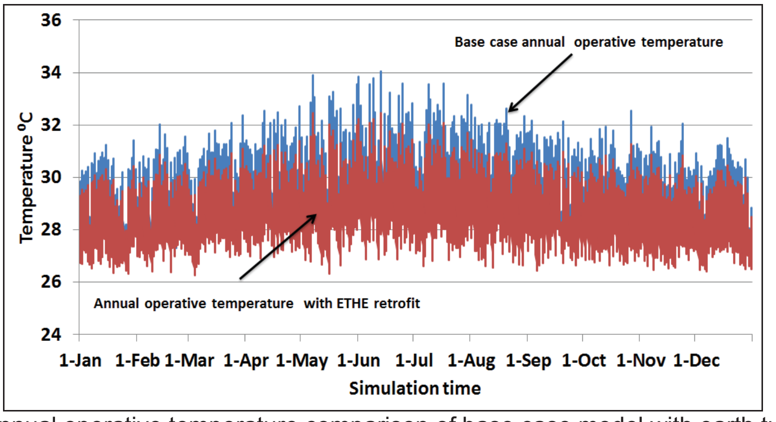


Figure 5. Annual operative temperature comparison of base case model with earth tube cooling system only

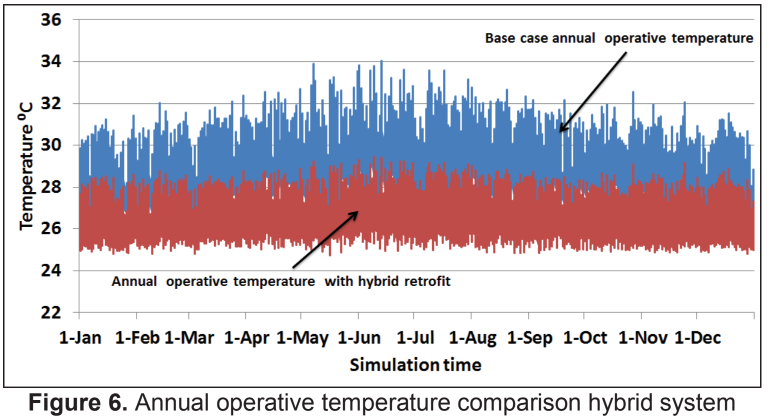


Figure 6. Annual operative temperature comparison hybrid system

Overall the hybrid system fitted to the building model provides significant cooling where building occupants can expect an indoor temperature of not more than 28.5ºC nearly 95% of the time all year. The hybrid system, in this case, is designed to improve both the indoor mean radiant temperature and mean air temperature, therefore, the overall operative temperature.

The simulation is also conducted for a design maximum dry bulb of 34ºC with an annual severity of 0.4% (the daily dry-bulb temperature that exceeds the design value about three hours in a month) for Kuching Sarawak as specified by ASHRAE (ASHRAE, 2014). Figure 7 shows the improvement in the operative temperature for a selected thermal zone which is a master bedroom of the building model. The base case hottest peak operative temperature is reduced from 33.5ºC to 29ºC with the application of the hydronic radiant system. Further reduction of another 2ºC is provided by the earth tube system leading to an operative temperature of about 27.5ºC.

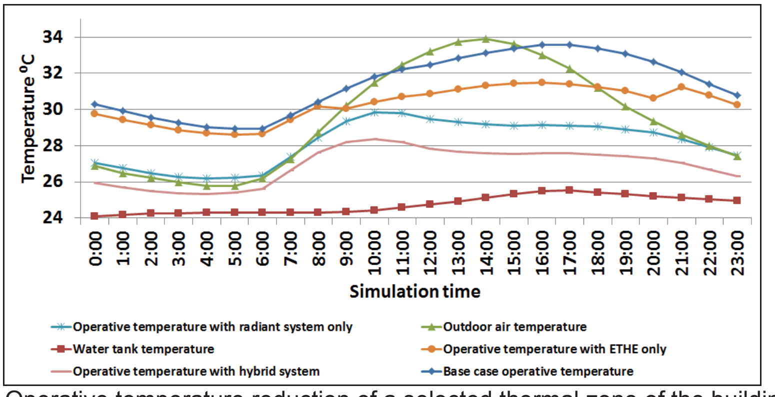


Figure 7. Operative temperature reduction of a selected thermal zone of the building model

The significant amount of cooling is possible with the usage of radiant system and earth tube system in place of a conventional air conditioning system. The radiant cooling system is integrated with a renewable source such as the night cooled water with a water temperature of as low as 24ºC. Upon use, the water temperature in the tank has increased to about 26ºC by 7 pm. By that time the recharging of the tank begins by the night cooling process until early in the morning.

For the same range of acceptable operative temperature, ASHRAE has specified that the thermal comfort range expressed as Predicted Mean Vote (PMV) index is between -0.5 and +0.5 on the thermal sensation scale. ISO 7730 allows for an extended acceptable range such as category C PMV of between -0.7 and +0.7 that could be set as criteria in design (ISO, 2005). Figure 8 shows the improved PMV after integrating the hybrid system into the building model. The base case PMV of 2.2 is greatly improved to 0.7 to meet category C PMV standard of ISO 7730. The calculated PMV is based on a clothing insulation value of 0.7 clo, room air velocity of 0.2 m/s, work efficiency of 0.3 as well as variable air humidity, air temperature and mean radiant temperature as calculated by EP using Kuching Sarawak weather data file.

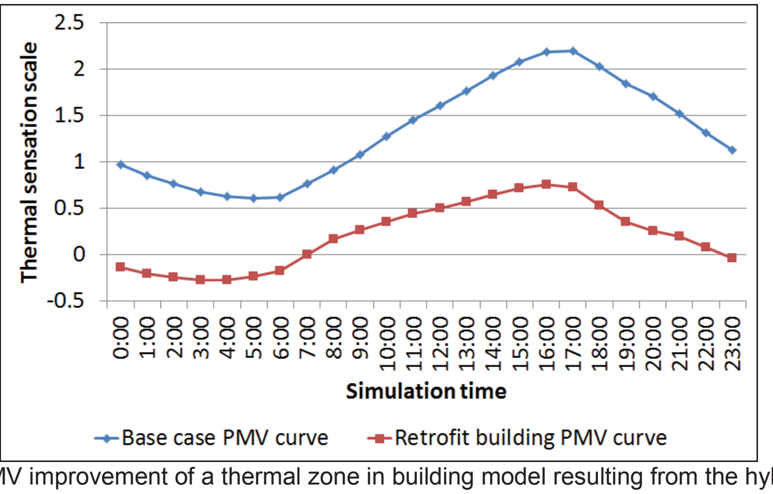


Figure 8. PMV improvement of a thermal zone in building model resulting from the hybrid system application

A minimal energy demand is required to operate the water pump in the radiant cooling system integrated with a renewable energy source. Additional power is also required to run the blowers associated with the earth tube system. Table 5 shows the saving in energy and money term that can be achieved by radiant cooling and earth tube hybrid in comparison to the conventional air conditioning system. The comparison between the conventional and the radiant cooling system is based on a similar output quality. The simulation shows that as much as 90.5% energy could be saved by the application of the hybrid system. This particular bioclimatic system uses renewable resource in the form of free night cooled chill water as well as the precooled air from readily available heat sink source. This level of saving is not impossible as mentioned by radiant cooling industries experts (Nielsen, 2012).

Table 5. Predicted energy savings for base case and retrofitted building model

Cooling system	Annual energy (kWh)	Yearly operation cost (RM)	Operation cost from base case (%)
Conventional air conditioning	25,969	7790.70	100
Radiant cooling with free night cooled water	2,480	744.00	9.5
Hybrid system	2,726	817.80	10.5

CONCLUSIONS

The focus of this study is on a bioclimatic approach in designing a more sustainable home that is environmentally friendly, meeting thermal comfort criteria and lower operation cost. An annual simulation using a simulation program shows that radiant and earth tube system hybrid which connect a building model to a natural heat sink source such as night cool sky and cooler ground subsurface can improve the indoor thermal condition of the building significantly. The design integrates the building site's microclimate and the active system; in this case the heat exchangers such as radiant panel, ETHE and the building roof itself. The result leads to a low energy building which also meets the human indoor thermal comfort needs.

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D3 SUSTAINABLE HOMES – AN ALTERNATIVE DESIGN FOR HIGH-RISE AFFORDABLE HOUSING IN TROPICAL CLIMATES

Foo Chee Hung[1], Zuhairi Abd. Hamid[1], Gan Hock Beng[2], Chong Raymond[3] and Chung Chai Yin[3]
[1]Construction Research Institute of Malaysia
[2]G&A Architect, Jalan Perda, Barat Bandar Perda, 14000 Bukit Mertajam, Penang, Malaysia.
[3]Sime Darby Property, Jalan PJU 1A/7A, Ara Damansara, PJU 1A 47301 Petaling Jaya, Selangor.

Abstract
Malaysia have witnessed massive housing development for the last three decades. High-rise residential projects have mushroomed across the urban landscape in Malaysia. There is, however, a limitation of architectural design theory for high-rise buildings, especially the passive design principles. The present paper aims to address this issue by proposing a flexible housing design system for the high-rise affordable housing in tropical country. The proposed alternative is a combined design and construction system that makes use of the open plan design concept and the Industrialized Building System (IBS) construction method, to produce a variety of housing design options that meet possible user requirements not yet identified at the design stage, while retaining principal uniformity to facilitate the execution of simple but accurate construction with a minimal initial cost. Such system is able to provide the physical spatial arrangements that are conductive for the socio-cultural wellbeing of a community along while complementing the environment. Besides, the system combines both machine production and mass customization, offering more than 10,000 possible designs including prefabricated structures, factory-made structures, dwelling plan and flexible design, to provide an affordable and sustainable housing for all. On a much larger scale, it can facilitate the shift towards higher quality housing in the country, and eventually provide a new dimension in the design of comfortable and sustainable housing for the tropical country.

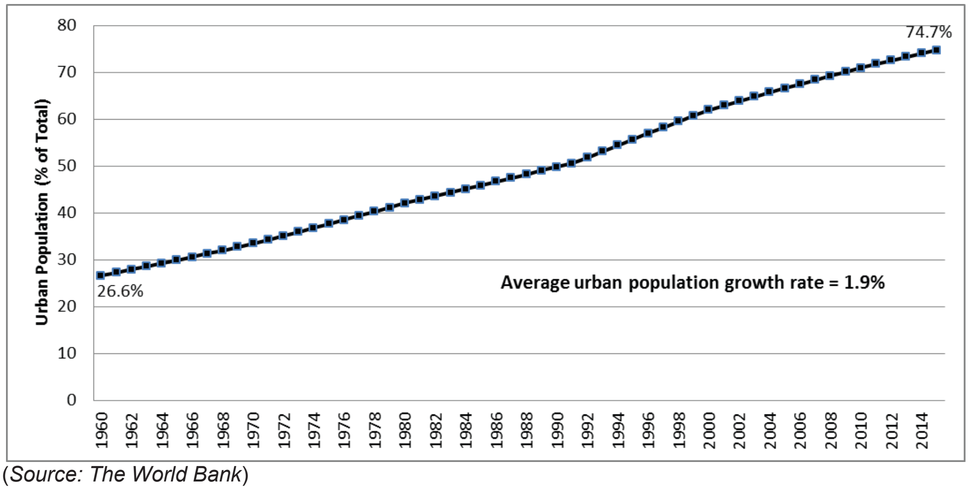
Keywords: *passive design, affordable housing, high performance building, tropical country*

INTRODUCTION

Housing emerges as a vital issue to the wellbeing of the community in many modern cities. This is especially true in countries like Japan, Singapore, and Hong Kong, where the lack of developable land in urban areas has made high-rise housing the mode of living for the vast majority of the people. High-rise housing has technical and economic advantages that enable it to form a distinctive feature of housing accommodation in virtually all densely populated urban areas around the world. Such housing type has the potential to decongest the urban sprawl on the ground level, as well as increase the urban density, and housing higher number of families in lesser space (Al-Kodmany and Ali, 2012). In contrast to the low-rise and single-family houses, high-rise housing is capable of accommodating more inhabitants per unit of area of land and decrease the cost of municipal infrastructure.

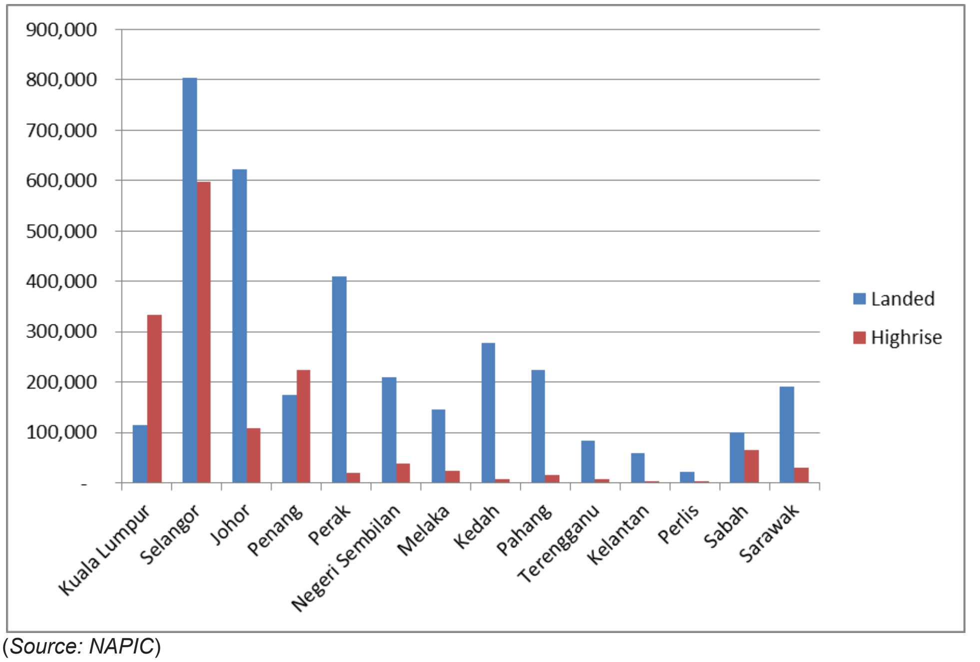
As in many other Asian countries, the urban growth in Malaysia has been rapid in the past decades. According to the report titled East Asia's Changing Urban Landscape: Measuring a Decade of Spatial Growth, Malaysia is one of the most urbanized countries of East Asia, with its urban land grew with an average annual growth rate of 1.5%, from about 3,900 square kilometers to 4,600 between 2000 and 2010. In terms of urban population, the rate is on the rise from 26.6% in 1960 to 74.7% in 2015 and is expected to surpass 80% by 2020 (Figure 1). There are 19 urban areas with more than 100,000 people in the country: one urban area of more than 5 million people (Kuala Lumpur), two between 1 million and 5 million people

(George Town and Johor Bahru), five of 500,000 to 1 million people, and 11 urban areas of between 100,000 and 500,000 people. Due to the country's rapid urbanization process, the construction of high rise development is obvious, especially for the limited prime land in states such as Kuala Lumpur, Selangor, and Penang. This can be seen from the increasing number of vertical residential developments being planned and built in most major cities of these states (Figure 2). In fact, high-rise developments have been sprouting in these major cities in the last decades, with the tremendous increment happened in Selangor, followed by Kuala Lumpur and Penang (Figure 3).



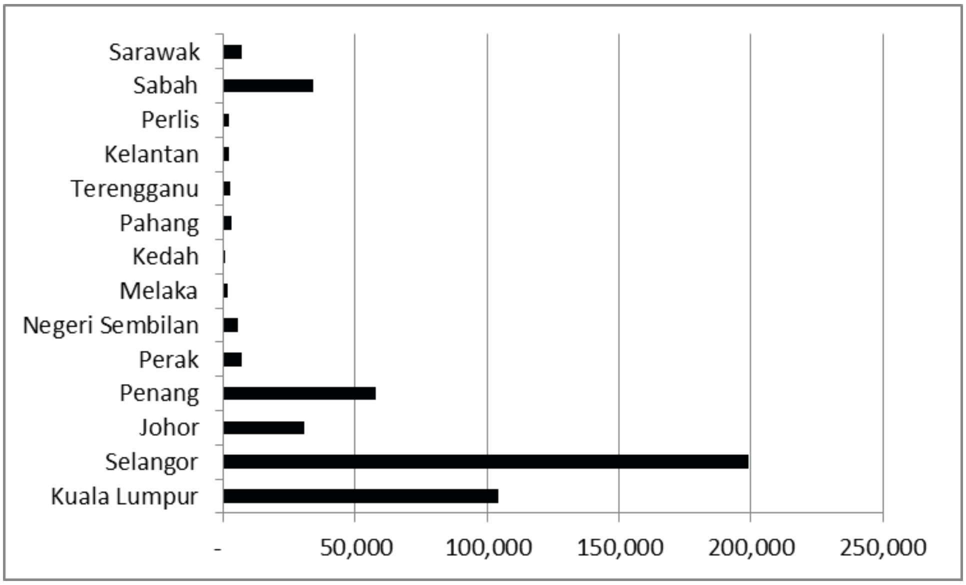
(*Source: The World Bank*)

Figure 1. Percentage of urban population in Malaysia, 1960 – 2015



(*Source: NAPIC*)

Figure 2. Total number of landed and high rise residential development by state in 2015



(*Source: NAPIC*)

Figure 3. Increment of high-rise development by state, 2005 – 2015

While apartment living seems to be the housing solution for densely populated areas, its environmental impacts are still a matter of concern. According to the report titled Residential Apartments Sustainability Plan: A plan to achieve environmental performance in new and existing apartment buildings, the utility consumption per person at a building level is greater in high-rise apartments than landed dwellings. This is particularly high in buildings with centralized plant and equipment and underground car parks, in which up to 60% of an apartment building's total energy is used in these common areas. The report also found that residents in apartment recycle half the amount that residents in single houses do, in addition to the extremely high-water consumption in apartment living as compared to the landed counterpart. In such a living environment where high density is inevitable, there are strong opinions that high rise development contributes to an urban pathology and social decay in residential areas, which could undermine the character, livability, social fabric and even the public health of a city (Wan Abd Aziz et al., 2014; Cappon, 1971).

Moreover, changes in the demographic make-up due to the diversity of family typologies and household arrangements have generated a need for housing that can adapt to different privacy, space, use requirements, and life styles. The present apartment housing, however, have rigid structure, interlocking plan, and predetermined function, in which very few of them can really satisfy the highly variable spatial needs of the various users. According to Karim (2012) and Isnin et al. (2012), users, especially in mass housing, are not satisfied with their housing conditions. Most of them end up making alterations to their units before moving in by knocking down brick walls and building new ones to form rooms that suite their requirements (Rostam et al., 2012; Nurdalila 2012; Erdayu et al., 2010). Criticisms have even been made upon the architectural design of the People's Housing Project Scheme (PHP) – an initiative by the government to solve the problem of existence slums and squatter areas – including the lack of storage area, small size and deep location of the kitchen, minimum external wall area, complicated partitions, less cross ventilation etc. (Sahabuddin and Gonzalez-Longo, 2015). Given the need for sustainability and the generally important consideration of environmental and social values in the longer term, proposing freedom to choose among options that fit individual needs and aspirations is indeed essential at the housing design stage. In this sense, flexible housing design can be a suitable solution that capable to fulfill the ever changing dweller's spatial requirements.

However, the major objection to flexible designs is that flexibility entails complex construction and hence higher costs – the economy of scale through repetition is the main reason inadequate standardized designs are being used in the first place (Wong, 2010). Besides, the theory of flexibility is still largely unconsidered in the realm of residential design, even though it has already been applied in office and commercial building developments (Habraken, 2008). Furthermore, Alegre and Heitor (2004) revealed that the capacity of the reinforced concrete building to allow for changes through the conversion of the spatial layout is limited by the construction system. It is under these circumstances that the present study is conducted, with the aim of proposing a housing design system that integrating housing design with industrial construction system. By adopting flexibility as the inherent architectural design strategy, the proposed system is able to provide the physical spatial arrangements that are conductive for the socio-cultural wellbeing of a community along while complementing the environment. Besides, the system combines both machine production and mass customization, offering more than 10,000 possible designs including prefabricated structures, factory-made structures, dwelling plan and flexible design, to provide an affordable and sustainable housing for all. It makes possible the creation of dwellings which may grow old yet without becoming obsolete; incorporating the latest design ideas and technologies, yet have a sense of history on the Malaysian housing design (the *rumah kampung* design); allowing the communities to live for generations, yet incorporating the potential of adaptation.

DIVERGENT DWELLING DESIGN (D3) SYSTEM

Divergent Dwelling Design, or D3 in short, is a combined design and construction system directly responses to the fundamental demographic and economic pressure that heightened the need for an appropriate solution for the urban mass housing. It makes use of the open plan design concept and the Industrialised Building System (IBS) construction method, to produce a variety of housing design options that meet possible user requirements not yet identified at the design stage, while retaining principal uniformity to facilitate the execution of simple but accurate construction with a minimal initial cost.

The proposed D3 basic architectural plan is a square shaped plot (Figure 4), having a plurality of "dynamic" space lots (where the bathroom, kitchen, and other dwelling services located) arranged peripheral of the plot so as to be in contact with the outdoor environment; and a plurality of structures such as the dining room, bedroom, or any other spaces located in the "core" space lot which is capable of being arranged, modified, and customized in plurality of designs according to the user's needs. While the plot is standardized to allow for efficient manufacturing, it can take any desired shape including square, rectangle, as well as other polygonal shapes (Figure 5). With the built-in architectural flexibility, D3 basic dwelling unit can be divided into more than one plan, in which the occupant can choose the floor plan they want to live before moving in, thereby achieving harmony between the basic structure and the various sizes of dwellings in the long term. This is similar to the automotive industry, where each individual functional unit is freely bonded with the core structure to serve different occupants' requirement.

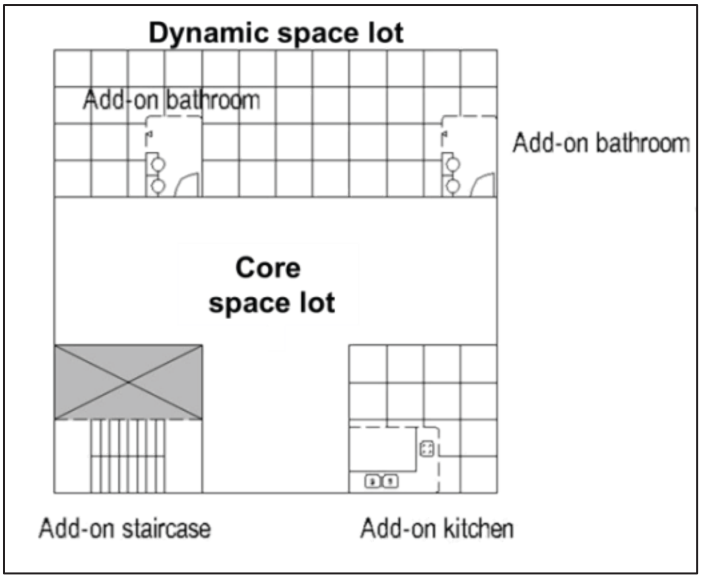


Figure 4. D3 basic architectural plan

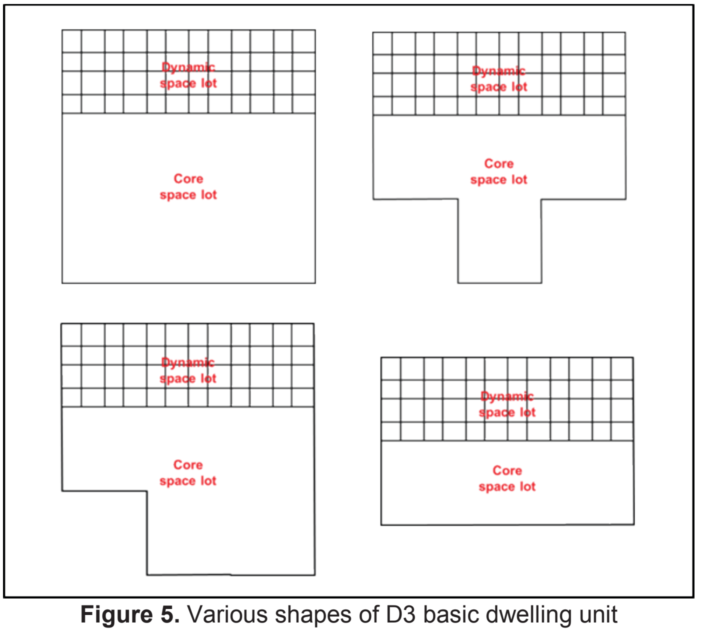


Figure 5. Various shapes of D3 basic dwelling unit

Every D3 building is designed and built in such a way that both the structure and infill of the building are treated as separate entities in order to optimize the efficiency of building assembly and modification. As depicted in Figure 6, the basic layout can be configured into various plans, simply by partitioning the core space lot or rearranging the location of bathroom and kitchen within the dynamic space lot. In other words, there is no one fixed plan in D3 design system but a flexible plan that houses endless of possibilities. Owning to the use of a number of interchangeable component sub-assemblies, D3 makes possible the transfer of construction process from building to manufacturing, with component manufacturers and end-users playing a much larger role in the design process. For example, the bathroom, kitchen, partition, façade etc. are mass produced which then divergently attached to the building structure (Figure 7). The occupant has wide spectrum of choice with regards to products in the market. Since each system is independently manufactured in a controlled environment, the development entails the use of technology and innovation, without the involvement of excessive site labour, time, and cost. In this sense, D3 comprehends the advances of science and technology over time, leading to a faster production at economical rate.

Once the design system is in tandem with serial production and standardization, there will be no bounds for the development of a sustainable community that can accommodate a wide diversity of users and household types. Prospective occupants can choose from a catalogue of available components which are tailored to individual lifestyles and budgets. This enables the occupants to consume only the type and quantity of features they currently require or can afford. For example, a variety of kitchen options that suit a wide range of household lifestyles can be offered by the manufacturers without significant increase of their administrative and operational costs due to the prefabricated nature of kitchen cabinetry. Besides, the variety of configurations available caters to desires for increased work surfaces, space economy, and the inclusion of washer, dryer and recycling facilities within the kitchen. Similarly, the bathroom requirements also vary according to the occupants and their individual scenarios. Normally, two bathrooms will be provided for every affordable house in Malaysia. However, the number of bathroom is not restricted in D3 housing; if the number of occupants and their schedules justify for another bathroom, D3 open plan concept would satisfy this requirement by balancing the size and location of this additional bathroom with the remaining spaces in the dwelling unit. Consequently, the bathroom options offered by D3 housing can range in size from powder rooms to complete bathrooms with shower, bath, toilet, and sink. Since every individual dwelling unit is flexible enough to adapt to the changing needs of both existing families and future users, the combination of these units will enable a variety of sustainable habitual spaces to be processed, which then can constantly renew themselves without becoming obsolete.

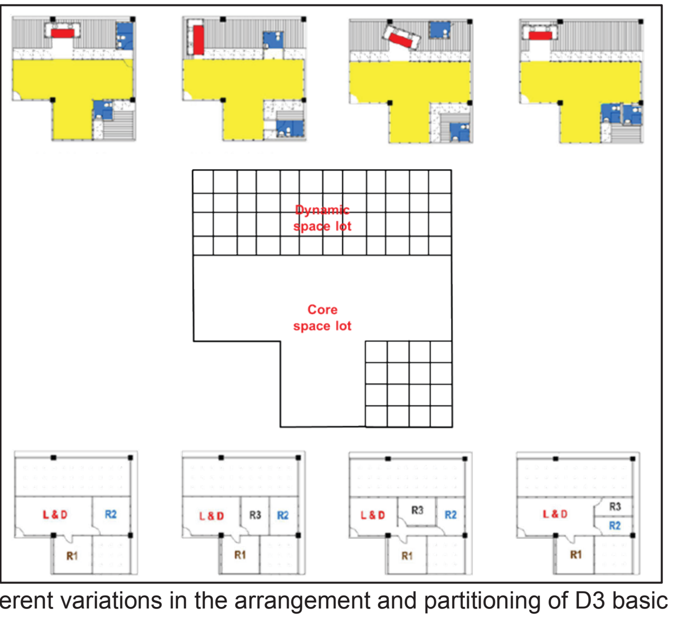


Figure 6. Different variations in the arrangement and partitioning of D3 basic dwelling unit

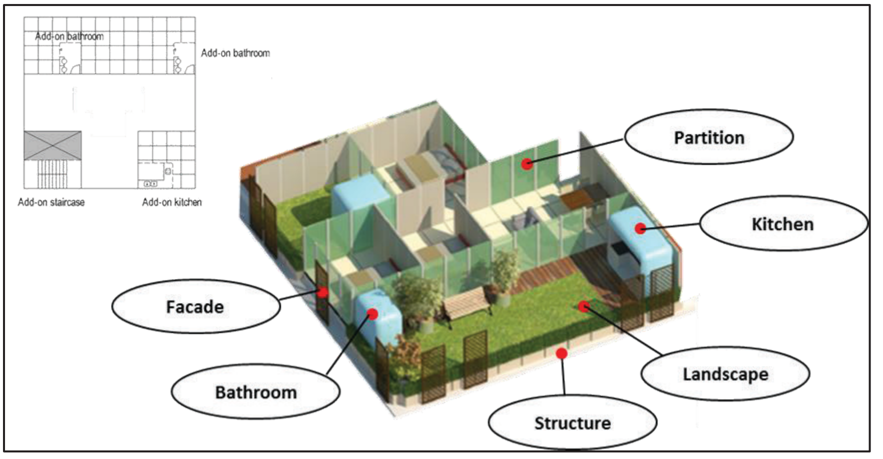


Figure 7. D3 independent building systems

The principles underlying the design of facades are analogous to those governing the structure and plan: flexibility and individual identity. By positioning the dynamic space lot in the peripheral of the plot, a setback of walls is created where no external walls to be in contact with the outdoor environment. Such setting can be well-adopted in the apartment development, imparting a sense of individual identity and differentiating vertical occupancies or uses, yet avoiding the extremes of monotony and theme park atmospheric elements (Figure 8). One of the most common drawbacks of prefabricated housing is the homogenous and repetitive nature of the development, which is a by-product of the economies of scale. The value of providing a diversity of appearances is that it satisfies the individual user's personal requirement for identity and self-expression, counteracting any potential feeling of anonymity resulting from increased density, and it incorporates – or rather predicts and pre-structures – the inevitable variety caused by change overtime.

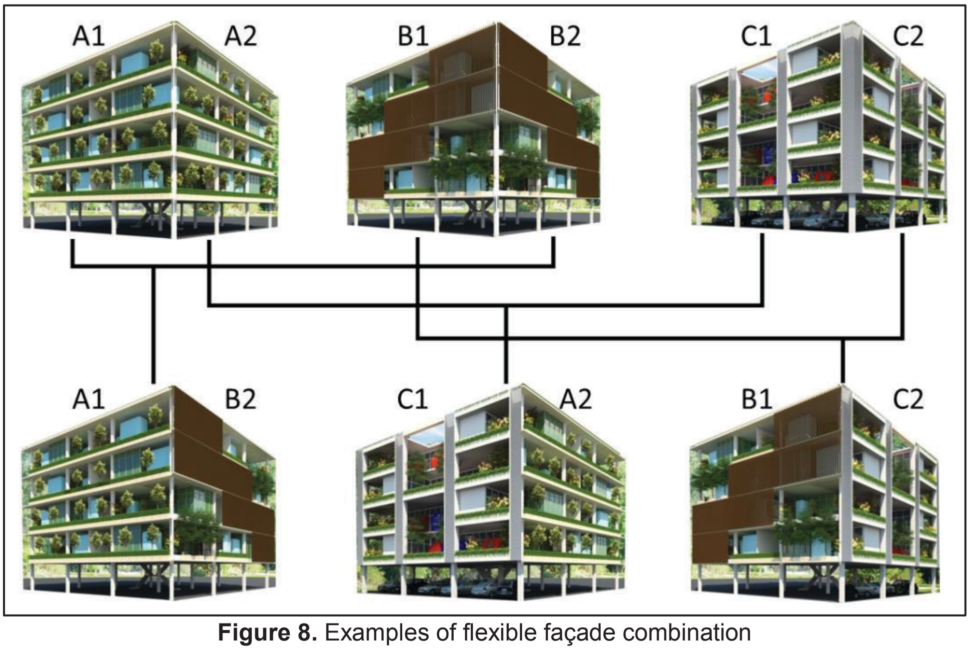


Figure 8. Examples of flexible façade combination

D3 CONSTRUCTION STRATEGY

Construction efficiency is among the most effective strategies for decreasing the cost of housing construction without reducing its liveability (Feldman and Chowdhury, 2002). In the case of D3 construction, a modular system prevails in an attempt to minimize building costs, as well as to execute simple but accurate construction. The 7.2m x 7.2m module allows for a strong element of flexibility with regard to a variety of building configurations (Figure 9). This unit module with its multiples and subdivisions form the basis of all dimensions of the dwellings. The advantage of the employment of this single unit module is that all locations and sizes of the parts with respect to the whole are precisely identified during the construction process (Figure 10), and thus, no obscure or arbitrarily unrelated measurements are involved in the unit system. This also leads to other advantage, such as the standardization of many building components (prefabricated beam, column, and slab) for mass production in manufacturing. There is usually a cost with the provision of a structure that allows for flexibility and adaptability. In a departure from the conventional mass housing design, however, D3 design system allows planners and builders to incorporate various housing types within a single unit module in order to respond to a diverse range of values, incomes, and households (Figure 11). With such ability, a wide range of housing size is covered under one design plan, be it a 450ft^2 studio type dwelling, 700ft^2 low-cost housing, or 1,000ft^2 affordable housing.

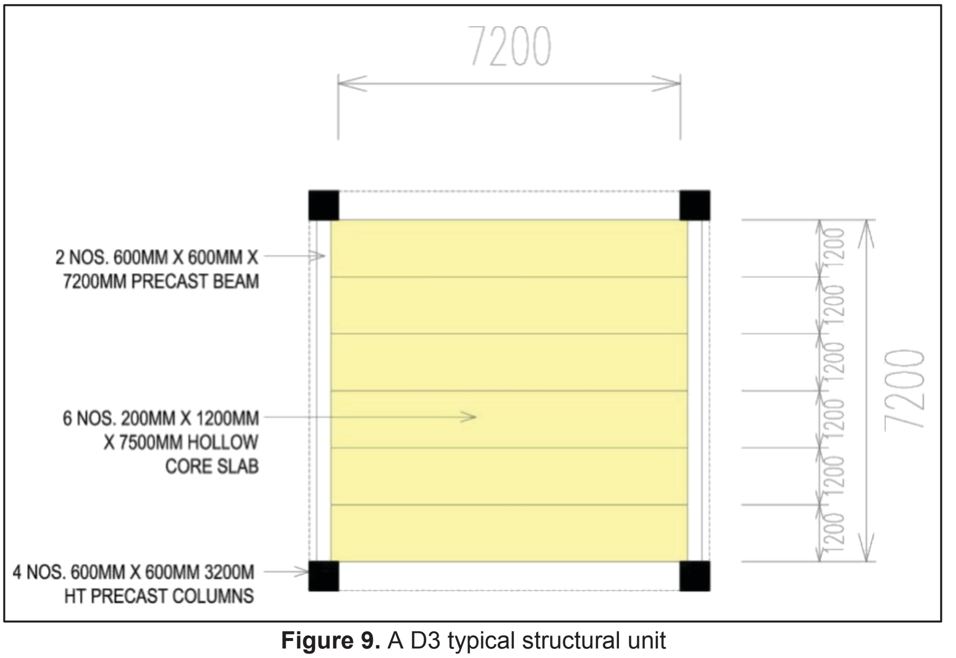


Figure 9. A D3 typical structural unit

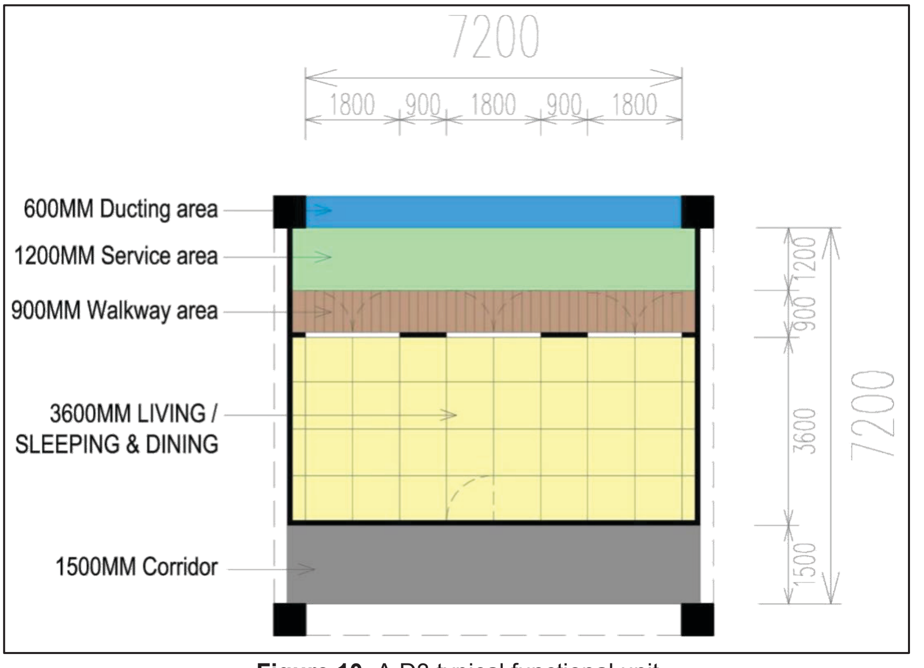


Figure 10. A D3 typical functional unit

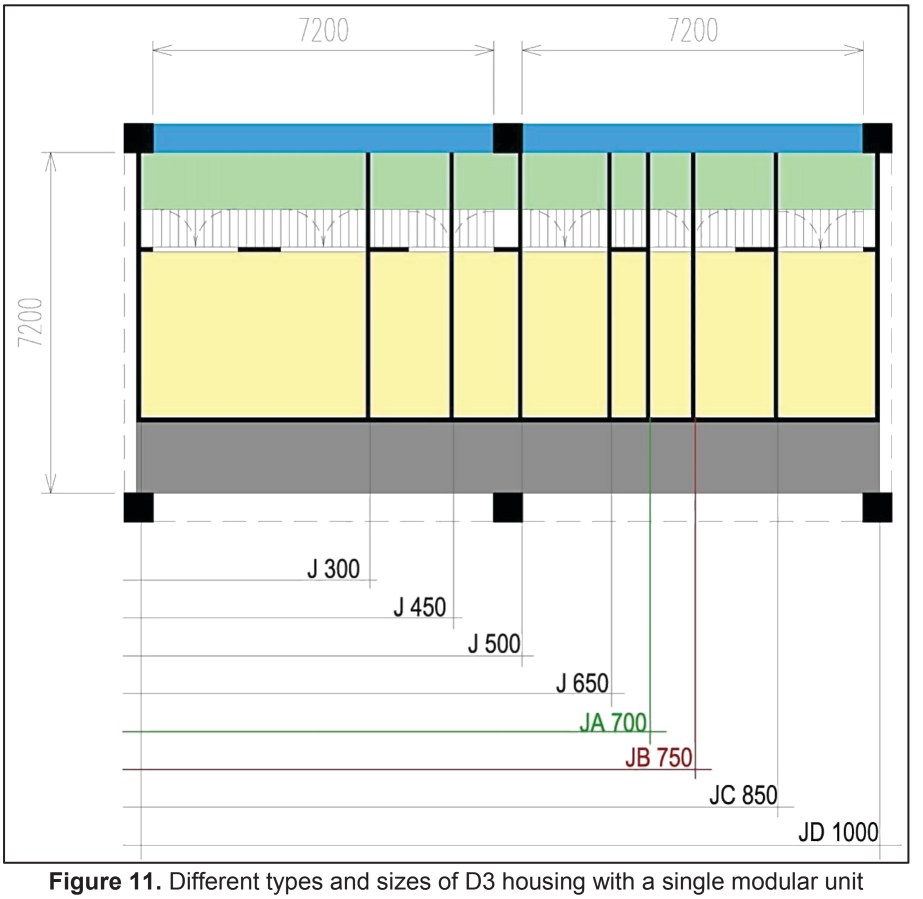
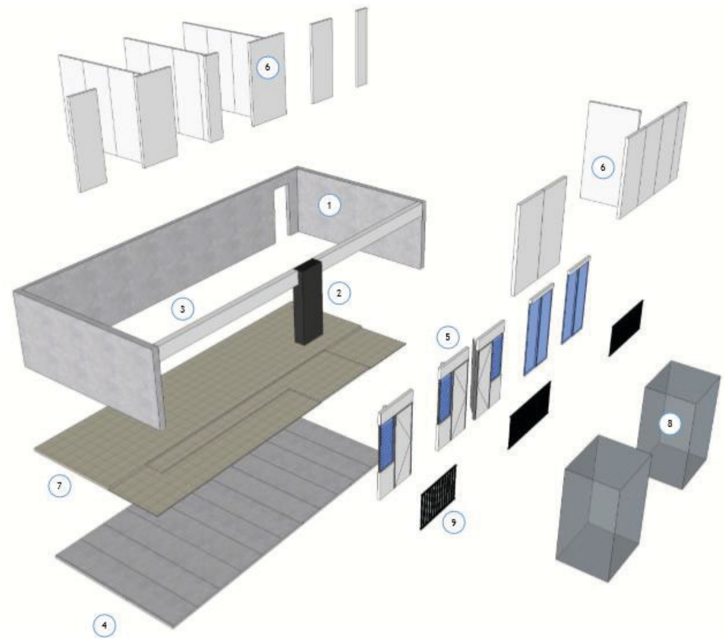


Figure 11. Different types and sizes of D3 housing with a single modular unit

All prefabrication of structural components is made in an off-site factory and is regulated with regard to the single unit module, namely column, beam, and hollow core slab. In an actual pilot project, which will be introduced in the later section, only 10 IBS components are needed for the construction of a typical D3 mass housing unit (Figure 12). When all components are delivered on site, they are assembled to become a home. Assemblage of components is easy and simple, where altering or replacing components is much the same. The construction system is a kit-of-parts solution to the affordable housing problem that does not require a highly skilled work force or special machinery. By incorporating IBS into the construction process, a compressed construction schedule is not only cost-saving in and of itself, getting the building into productive use sooner and reducing finance periods, but, especially in times of significant inflation, compressed construction schedules save additional significant sums. Therefore, a building that adopting D3 design system can be constructed at a faster pace and arranged in multiple manners, to achieve high density in the most comfortable spatial design environment.



1. Cast in situ sheer wall (250mm thick) 2. Precast column (450mm x 1100mm) 3. Precast beam (250mm x 550mm) 4. Precast plank slab (150mm x 1200mm x 6500mm) 5. Prefab aluminum sliding door (1600mm x 2100mm)	6. Precast concrete wall panel (100mm thick) 7. Ceramic floor tiles (400mm x 400mm) 8. Prefab toilet/bath unit (1550mm x 1950mm x 2350mm) 9. Prefab railing (1200mm) 10. Plumping and M&E

Figure 12. IBS components for a typical unit of D3 mass housing

D3 SUSTAINABLE STRATEGY

Malaysia is situated in a maritime equatorial area, where the climate is generally the same throughout the year, with uniform temperatures, high humidity, light winds, and heavy rainfall (Hyde, 2008). The very nature of the Malaysian climate necessitates mechanically ventilated or air-conditional interiors, especially in urban areas. However, poor design and indiscriminate use of air conditioning have resulted in huge increases in energy use. Passive and low energy design strategies are too often excluded from the affordable housing projects because they are deemed to add cost to the construction, though they are the solutions for a sustainable future. In fact, it is possible to attain energy efficiencies without incurring additional costs. As pointed out by Feldman and Chowdhury (2002), energy efficient design contributes to environmental sustainability and saves life-cycle costs. D3 directly responds to the fundamental demographic and economic pressure that has heightened the need for a new housing alternative which appropriately integrates affordability and sustainability. To ensure mass housing populations could enjoy eco-housing with affordable price, affordability is designed in at the beginning by adopting a simple design layout, which is flexible enough for adaptation and yet suits to the tropical climatic condition.

The passive design strategies adopted in D3 design system is inspired by numerous features found in the traditional Malay house that area geared towards providing thermal comfort. With a direct dependence on nature for its resources and embodying a deep knowledge of ecological balances, the traditional Malay house is best reflecting the bioclimatic housing, using various ventilation and solar-control devices, and low-thermal-capacity building materials (Figure 13). Apart from being well adapted to the environment, a very sophisticated addition system was also developed to allow the house to be extended in line with the growing needs of the user. Such an autonomous housing process, which is using self-help and mutual-help approaches, can throw some light on the development of a modern autonomous housing model. In general, the experiences gained from the traditional Malay house evidenced that an appropriate house in tropical country should provide for the following: (i) allow adequate ventilation for cooling and reduction of humidity; (ii) use building materials with low thermal capacity so that little heat is transmitted in to the house; (iii) control direct solar radiation; and (iv) control glare from the open sky and surrounding.

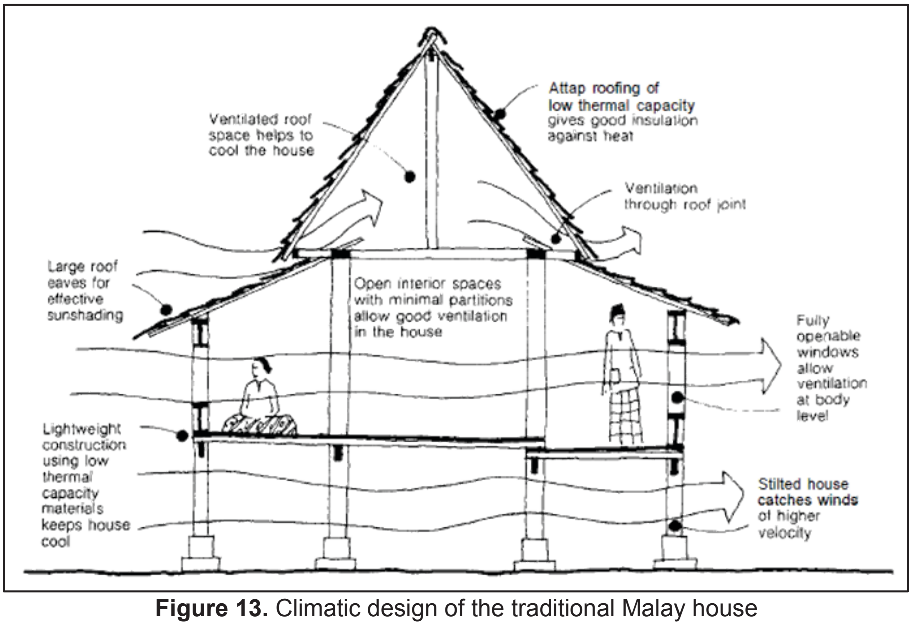


Figure 13. Climatic design of the traditional Malay house

In the case of D3 design system, cross ventilation is optimized by having an elongated dwelling shape together with minimal partitions or interior walls. This is not only allowing for easy passage of air and cross-ventilation, but also encouraging a good lighting of the interiors, as well as the flexible use of space. Besides, the parallel arrangement of windows and the placement of high louvers on the internal walls of each bedroom also ensure adequate wind from outside flows through the house. By setting back the exterior walls 8ft from the peripheral of the dwelling, no walls are exposed directly to the outdoor environment. Solar radiation is, thus, effectively controlled with the large thatched upper floor ceiling that acts as the overhang. Together with the installation of adjustable louvres or grilles as building façade, a barrier is created which not only provides good shading and protection against driving rain, but also to some extent maintain the quality of openness for ventilation and outdoor views.

The setback also creates an open porch that makes possible the occupants to enjoy the open-air landscape. With careful planting or selection of vertical green, the open porch can function as a buffer corridor that aids in air circulation. The presence of air movement will then enhance the evaporative and convective cooling from the skin and can further increase the occupants' comfort. Glare, which is a major source of stress in the tropical climate, is effectively controlled by using louvres or grilles which break up large bright areas into tiny ones and yet allow the interiors to be lighted up; or by planting less reflective vegetation. Figure 14 illustrates the interior views of the D3 housing.

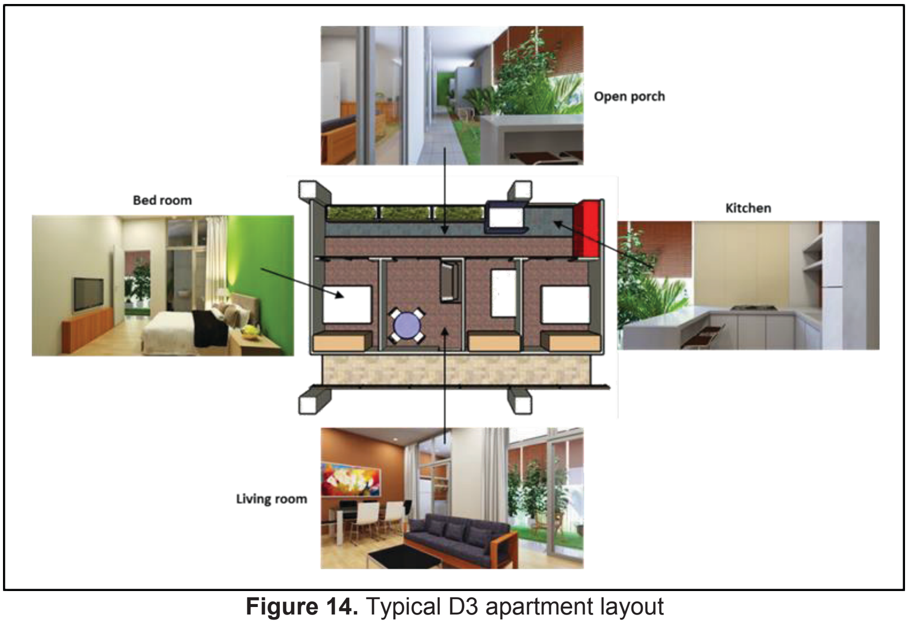


Figure 14. Typical D3 apartment layout

The use of reinforced concrete skeleton structure ensures a lot of the qualities that aid flexibility in housing design, which then contribute to the housing affordability and sustainability. First, prefabrication construction allows for the design of flexible internal space layout are variable to accommodate different family structures. The constant improvement in prefabrication technology that supported by the incorporation of lightweight, durable, smooth edged, space efficient, and universally adopted specifications will ensure that mass housings remain affordable and sustainable for the long term. Second, the use of concrete as the main structural material contributes to a wide range of inherent benefits at no extra cost, such as its proven integral fire resistance, high levels of sound insulation, and robust finishes. Through its very nature, concrete provides robust surfaces for walls, partitions, columns, soffits and cladding that are easily sealed and free of ledges or joint details. All these may finally lead to the lower maintenance costs of the building while set in motion an efficient, cost effective and practical method for solving housing needs and overcrowding concerns in urban areas. However, realizing that the concrete industry is responsible for 10% of worldwide CO_2 emissions, the limited use of concrete is also to be considered in D3 design system. For example, complicated wall arrangements are avoided in D3 housing, so that less concrete wall panels are used as internal partition. Within a typical D3 dwelling unit, walls that facing the outdoor environment is eliminated with the installation of aluminum sliding doors. Since the infills of D3 housing are prefabricated materials that are subject to change, lightweight materials that have a low heat storage capacity such as gypsum board and plasterboard with insulation can always be used in replacement of the existing one. In short, flexibility in terms of architectural and construction process is the key strategy of sustainability in D3 housing.

D3 PROJECT IMPLEMENTATION

Affordable homes are a major concern for potential homeowners today and will likely remain so tin the future, given the recent housing boom in Malaysia. For some, house prices have increased in urban areas beyond the means of low and middle-income groups and first-time buyers. Having a supply of affordable housing close to economic and employment centers is vital to both the economy and community wellbeing as it means people can live near their jobs, traffic congestion can be is eased and the cost of commuting is reduced. The supply of affordable homes in many areas falls short of the demand for it, potentially consigning the urban poor to further generations of poverty and the social problems that come with this issue. In order to tackle this, Sime Darby Property (SDP) – the developer with the largest land bank in Malaysia – is playing a role in supporting the government through the provision of affordable housing.

SDP is committed to be the country's first sustainable developer, in which the organization seeks to achieve excellence in all its business engagements without compromising its commitment to improvements for people, planet and prosperity. SDP aims to provide customers with the best quality affordable homes by being the first developer to adopt the D3 concept, which offers an innovative advantage. On 26th January 2017, a memorandum of agreement was signed between SDP and the Construction Research Institute of Malaysia (CREAM), with the aim to commercialize the D3 affordable housing design concept, as to improve affordable housing with new methods of design and construction. This collaboration also serves part of the innovative efforts of the organization, which is to focus on various aspects of our products including affordability, adaptability, quality and sustainability.

Dubbed as 'Sime Darby Property D3 Sustainable Homes', D3 is poised to transform affordable housing nationwide by improving the quality and standards of affordable homes and lifestyle. This innovation elevates the organization further as a significant developer of affordable housing in Malaysia and a socially responsible company that fulfils the affordable housing needs of the nation. To introduce the innovative D3 concept to consumers, SDP is building a D3 prototype gallery at the Elmina West Township in the City of Elmina, Shah

Alam. The gallery will feature two affordable home show units – both with 900ft^2 and 1000ft^2 – which will be completed by mid-2017 (Figure 15).

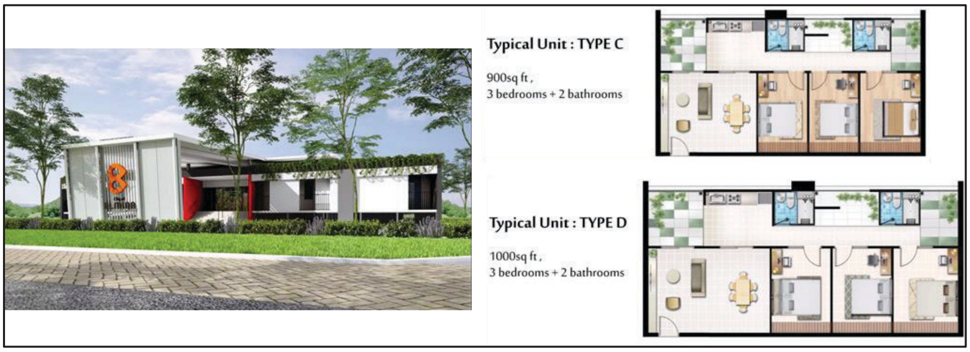


Figure 15. D3 prototype gallery

SDP will then develop the pilot project – *Harmoni 1 Pangsapuri* (Figure 16) in the same township, which is expected to commence by the third quarter of 2017. This project will be the first statutory affordable housing project to adopt the D3 concept, consisting of 562 apartment units with sizes between 900ft^2 and 1000ft^2 and complemented by shop office units. With this pilot project, both the SDP and CREAM hope to introduce the D3 housing design system to the construction industry, which will lead to rapid construction, shortened construction time and fast product delivery to consumers. Conventional affordable housing projects require about 36 - 42 months of construction time, while D3 combined housing design and construction system has the potential to be completed within a period of 24 - 30 months, 28% – 33% faster than traditional methods.

Figure 16. D3 pilot project – *Harmoni 1 Pangsapuri*

CONCLUSION

With increasingly rapid transformation of the life-style of residents, user preferences outgrow the capacity of buildings faster than ever before. Residential housing, especially mass housing that is not designed to satisfy immediate needs only will eventually become obsolete when they can no longer serve the users' changing needs.

D3 design system introduced here can generate a better and cheaper habitat option through the application of existing science, technology and machine production capability. D3 presents a scientific plan which maximizes usable space, provides distinctive zones for effective space planning, allocation of areas for urban farming to promote sustainability, and optimizes natural ventilation. The use of modular construction components safeguards product quality and eliminates leaking problems. Mass production of modular components reduces production cost and promote more savings. D3 also features simple assembly. Prefabricated components such as toilet pods, floor slabs, columns and beams and concrete wall panels facilitate easy plug-in and plug-out application, ensuring accuracy, fast assembly at site and lower labor dependency. Finally, a flexible layout which provides the flexibility for occupants to modify their units according to the different needs at different times.

This alternative housing design concept is able to provide a new dimension in the design of comfortable and sustainable housing for the tropical country. The importance of this housing solution is reflected in its ability to solve the housing problems of especially the poor in a manner that is most appropriate to their socio-economic and cultural needs, by using environmental friendly method, contribute to the sustainable development of the construction industry, offers what people demand from a house and that they can live how they want to within it, by taking into account (i) the spatial and functional arrangement, (ii) the potential to expand spaces for increased occupant's usage, (iii) maximizing natural lighting and ventilation, (iv) the continuity of the traditional housing concepts into a modern contemporary residential development. On a much larger scale, D3 can facilitate the shift towards a higher quality housing in the country, and eventually create sustainable dwellings for everyone in anywhere in the country.

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APPLICATION OF BUILDING INFORMATION MODELLING (BIM) IN DESIGN AND BUILD (D&B) PROJECTS IN MALAYSIA

Juliana Brahim[1], Aryani Ahmad Latiffi[1] and Mohamad Syazli Fathi[2]
[1] *Faculty of Technology Management and Business, Universiti Tun Hussein Onn Malaysia (UTHM), 86400 Parit Raja, Batu Pahat, Johor, Malaysia*
[2] *UTM Razak School of Engineering and Advanced Technology, Universiti Teknologi Malaysia (UTM), 54100 Kuala Lumpur, Malaysia*

Abstract
Design and Build (D&B) is one of the most suitable types of project delivery method that are being used to implement BIM. However, there is a lack of documented evidence to show on how BIM is being implemented in D&B project. This paper aims to explore the current practices of BIM in D&B projects in the Malaysian construction industry. A literature review was done to explore on application of BIM in construction projects and D&B project concept. Furthermore, semi-structured interviews with construction players were conducted as a primary data for this paper. The interviews were conducted with construction players that are currently involved and have experiences in D&B BIM projects. The findings revealed that the BIM process in D&B projects is much similar with activities in conventional D&B project. The differences were by the used of BIM software, the process of developing project design into a 3D model and the involvement of BIM related designation in the project. In addition to that, the process of BIM in D&B has been highlighted in this paper.

Keywords: *Building Information Modelling (BIM), Design and Build (D&B), Current Practices, BIM Uses, Construction Players, Malaysia*

INTRODUCTION

For the past ten years, projects over budget, projects delay, and poor quality of projects are among the common problems that have been faced by the construction industry (Nagalingam, Jayasena and Ranadewa, 2013). These problems happened due to several challenges. In particular, the use of 2-Dimensional (2D) information in producing design contributed to the problems (Saini and Mhaske, 2013); thus, contributed to the miscommunication, duplication of information, and inaccurate of information among construction players (Zakaria et al., 2013). Most importantly, the involvement of various construction players in the conventional practice projects may also contribute to problems (Bryde et al., 2013; Crotty, 2013; Zakaria et al., 2013). This is because client, architect, C&S, and MEP engineers are working independently in producing the project design without coordinating their work with others (Crotty, 2013).

Hence, a massive gains need to be made in integrating all project teams with the structure of business lifecycle in construction industry that are being recognised by various project team (Marshall-Ponting and Aouad, 2005). In addition, the use of Information, Communication, and Technology (ICT) could also help to simulate a more standardised communication among construction players in construction projects (Ahuja, 2009). Otherwise, the current continuous problems in the industry could not be improved (Alaghbandrad et al., 2015). Based on that reason, Building Information Modelling (BIM) provides a solution to overcome the problems in effective and efficient ways by integrating BIM processes with the use of BIM software.

BIM is considered as a project and process simulation (Bryde et al., 2013; Kensek, 2014; Alaghbandrad et al., 2015) because it is a concept that could virtually show the planning and actual building of construction projects in 3-Dimensional (3D) modelling (Barnes andDavies, 2014; Kensek, 2014). Therefore, BIM could not be treated merely as a software tool. The use of BIM software must give impact on all processes within the construction projects (Azhar, 2011; Bryde et al., 2013). Thus, the benefits and resource saving during design, construction, maintenance, and operation of project has rendered a growing interest to adopt BIM in construction projects (Forbes and Ahmed, 2010; Arayici et al., 2012). BIM has been implemented in several types of project delivery method such as Design-Bid-Build (DBB), Design and Build (D&B), Construction Management (CM) (Eastman et al., 2011; Barnes and Davies, 2014), and Integrated Project Delivery (IPD) Method (Eastman et al., 2011; Porwal and Hewage, 2013; Kensek, 2014). Above all, D&B proved to be the most proficient and suitable type of project delivery method for BIM implementation (Eastman et al., 2011; Tsai, et al., 2014; Tsai, et al., 2014; Hardin and McCool, 2015), and it is easy in controlling and getting the full benefit of using BIM.

Despite its advantages, documented research that demonstrated on how well construction players implement BIM in D&B project and to what extend construction players use BIM in the D&B projects are still lacking. Therefore, this paper aims to investigate on the current practices of BIM in D&B project, specifically in the Malaysian construction projects. Literature review on the implementation of BIM and D&B concept are discussed in the next section.

LITERATURE REVIEW ON IMPLEMENTATION OF BUILDING INFORMATION MODELLING (BIM) IN PROJECTS

The use of BIM application has been expanded over construction project life cycle. It is used to achieve a better integration of project information, improvement of process in projects, and promoting collaboration from the pre-construction phase to post-construction phase (Barnes and Davies, 2014). Figure 1 shows the use of BIM application in construction projects.

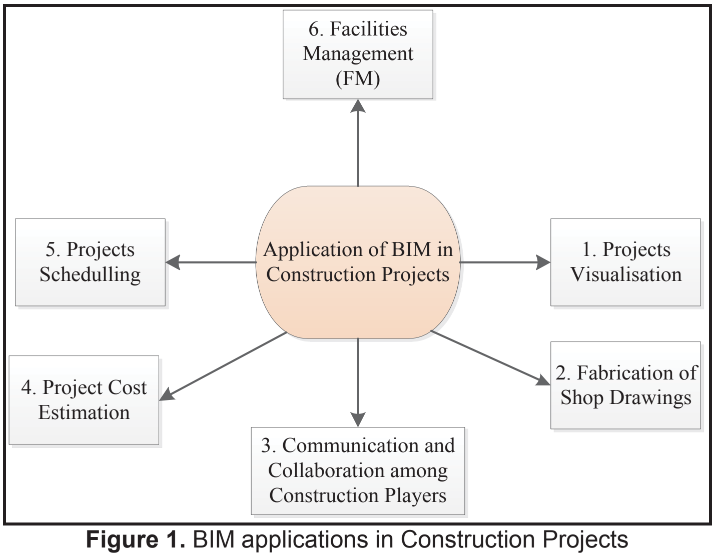

Figure 1. BIM applications in Construction Projects

Based on Figure 1, there are several common BIM application in construction project which are projects visualisation, fabrication of shop drawings, communication and collaboration among construction players, project cost estimation, project scheduling, and Facilities Management (FM) (Azhar, 2011; Bryde et al., 2013). Details of each application are discussed as follows:

Projects Visualisation

BIM helps construction players such as client, architect, civil and structural (C&S) engineer, mechanical, electrical and plumbing (MEP) engineer, quantity surveyor (QS), contractor and facilities manager to visualise a project before it project enters construction phase (Forbes and Ahmed, 2010; Azhar, 2011). By using BIM software, construction players specifically architect, C&S and MEP engineer are able to design and represent buildings with its component in a coordinated scale 3D model (Arayici et al., 2012). They commonly use BIM software such as Revit Architecture, Revit Structural, and Revit MEP to produce project design (Eastman et al., 2011; Hardin and McCool, 2015).

Fabrication of Shop Drawings

BIM can also be used to generate shop drawings faster compared to traditional practice, which is in 2-Dimensional (2D). In the traditional practices, any changes in a design must reflect the assembly drawings. By using BIM, any changes will be entered into the 3D model and the erection is updated followed by the automatic generation of shop drawings. This makes the shop drawings produced to be more accurate with less time and effort as the construction players especially architect, C&S, and MEP engineer do not have to update the information manually (Eastman et al., 2011).

Communication and Collaboration among Construction Players

BIM also increased communication and collaboration among construction players during the process of construction (Latiffi et al., 2013; Eadie et al., 2015). On top of that, BIM allows facilitating simultaneous work by multiple design disciplines (Eastman et al., 2011). By having communication and collaboration among construction players, high level of information transparency among them could be achieved by using BIM. As a result, the construction players could communicate and review the project information, gives feedback, and make decision regarding the project in less time than conventional construction.

Project Cost Estimation

In addition, BIM provides capabilities to extract the counts of components, area and volume or spaces in building, materials quantities and later to be used to determine construction project's cost as well as for construction planning and management (Eastman et al., 2011; Barnes and Davies, 2014). A QS uses BIM software such as Exactel Cost-X and Vico Take Off to generate an accurate quantity take off and estimation (Monteiro and Martins, 2013). These tools provide varying levels of support for automated extraction and manual take off features (Eastman et al., 2011). By using BIM software, QS is no longer carry out manual estimation. Therefore, the quantities and cost estimation produced in a project using BIM is more accurate and reliable.

Projects Scheduling

BIM could also be used to manage the schedule and planning of the construction projects (Hardin andMcCool, 2015). A project manager and contractor for instance, uses BIM software such as Autodesk Naviswork to provide 4-Dimensional (4D) scheduling, to update and track the progress of work, to create a multidiscipline model, to simulate and optimise scheduling, and to identify and coordinate clashes projects (Eastman et al., 2011; Latiffi et al., 2013).

Facilities Management (FM)

BIM is not limited to design and construction activities. It could also be used to maintaining the operation of building. Maintaining the information regarding the FM is much similar to maintaining the real facility. Facilities Manager uses BIM to upkeep, support, and maintains the completed building. Any components that replace, repair, remove or change will need to be up-dated (Bonanomi, 2016). Hence, the benefit of BIM for facilities management enable it to have an accuracy and up-dated building information model such as furniture, fixture, and equipment as well as the building occupants move in (Kensek, 2014).

Design and Build (D&B) Concept

Design and Build (D&B) is the most common type of project delivery methods that are being used in projects using BIM (Linderoth, 2010; Eastman et al., 2011). It is used to overcome the failures of traditional construction delivery methods of construction project (DBB) (Gould and Joyce, 2009; Forbes andAhmed, 2010). It is a concept where the contractor and the design consultant (architect, C&S, and MEP engineer) are in the same team in producing the design as well as contract documents based on the client's requirement (Porwal and Hewage, 2013). D&B entity or team takes the responsibility for the major design and construction activities, together with the risk associated in a fixed fee (Barnes and Davies, 2014).

Figure 2 shows D&B contractual relationship and work process in conventional construction projects.

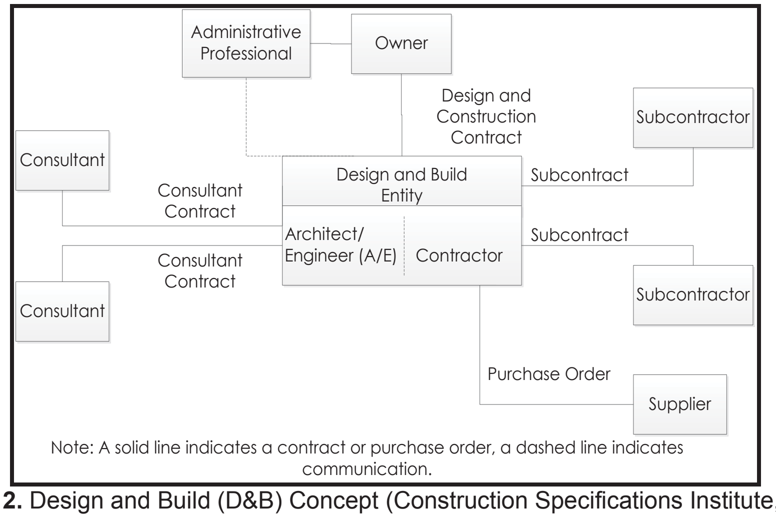

Figure 2. Design and Build (D&B) Concept (Construction Specifications Institute, 2011)

Based on Figure 2, a project client or owner is responsible to prepare project description. The description of project will be developed by an administrative professional in a separate entity. Meanwhile, the selected D&B team has an obligation to perform and deliver completed project based on the client specification. Commonly, the main contractor in the D&B team has its own design team which is architects and engineers (A/E) to offer D&B service to the client (Dobelis, 2013).

The A/E is responsible to develop project design including reviewing the client's project description, preparation of preliminary design, detail design, and preparation of construction documents. Once the design is completed with an estimated cost, D&B team will hire a sub-contractor and suppliers to construct the project (Construction Specifications Institute, 2011). In return, the D&B team will return a completed project to the client.

Hence, a collaborative work that occurs in D&B project delivery method is more suitable to facilitate BIM (Eastman et al., 2011; Eadie et al., 2013). This is because D&B method allows to have an early involvement of construction players and allow for modifications to be made early in the design process. For that reason, the project could save time and money.

METHODOLOGY

Data gained to achieve the aim of this paper was by means of literature review and semi-structured interview. A literature review was done to get explicit information regarding BIM uses, D&B concept, and the process involved.

Due to the limitation of construction players that involved in projects using BIM, a total of twenty-six (26) respondents have been identified to provide information related to BIM. A semi-structured interview with the twenty six (26) respondents that involved in BIM project have been conducted to get an in depth understanding on BIM process. As a result, eleven (11) of the respondents were found to involve in D&B projects. Various designation of respondents have been identified which are client, architect, C&S engineer, contractor, and BIM consultant.

The interviews were conducted to gain in-depth information on the involvement of various construction players in D&B projects using BIM, their experiences, BIM uses, and the process involved. The processes were by means of activities and sequences of work in implementing BIM. Those respondents were selected based on their willingness to share their experience.

A set of an interview questions was developed to obtain information on the process of D&B BIM project in the Malaysian construction industry. The interview questions consist of two (2) sections as shown in Table 1:

Table 1. Interview Questions

No	Section	Purpose
1	Section 1: Respondents' Background	• To identify respondents' designation in D&B project. • To get explicit information about respondents regarding years of experience in D&B projects using BIM.
2	Section 2: Current Practices of BIM	• To identify the purposes of using BIM in D&B projects. • To gain information on how BIM is being implemented by using D&B concept.

The interviews were recorded with permission from the respondents. Data gained were analysed by using content analysis technique. Content analysis is relevant to be used for analysing unstructured data such transcription of semi-structured interview. All data gained from the respondents were then analysed using Atlas t.i.7. Atlas t.i. enables to analyse visual and hierarchical modelling of concepts and theory. It merged with large amount of documents and keeps the data in all fields that require close study and analysis of primary material consisting audio, images, codes, video, and geo data (Ahmad Latiffi et al., 2016). All data were represented in the form of tables and figures.

The next session discusses on the findings and discussion on the respondents' experience, BIM uses and D&B process in the Malaysian construction projects.

FINDINGS AND DISCUSSION

The implementation of BIM as a new concept in construction projects could change the current activities and process of construction players in a project (Bryde et al., 2013; Hardin and McCool, 2015). This section focused on the findings from the interviews with construction players in D&B BIM project. This section consists of 4 sections as follows:

Respondents' Background

Respondents' background is important to ensure the selected respondents were appropriate to give information regarding BIM implementation in construction projects. From the data collected, all respondents' designation involves in D&B BIM projects were identified and presented in Table 2.

Table 2. Respondents' Designation in D&B Project using BIM

Respondent	Designation				
	Client	Architect	Civil and Structure Engineer	Contractor	BIM Consultant
R1					•
R2				•	
R3					•
R4				•	
R5				•	
R6		•			
R7		•			
R8					•
R9	•				
R10			•		
R11					•
Total	1	2	1	3	4

Based on Table 2, one (1) respondent (R9) held designation as a client. Two (2) respondents (R6 and R7) are an architect. Meanwhile, one (1) respondent (R10) is C&S engineer. Conversely, three respondents (R2, R4 and R5) involved as a contractor and four (4) respondents (R1, R3, R8 and R11) involved as a BIM consultant in project using BIM. Four (4) respondents (R1, R3, R8 and R11) involved as a BIM consultant.

Respondents Experience in Implementing Design and Build (D&B) BIM Project

The purpose of this section is to explore on the duration and inception of BIM implementation among respondents in D&B projects. Table 3 shows the respondents' experience in D&B project using BIM.

Table 3. Respondents' Experience in D&B Project using BIM

Respondent	Designation									
	2015	2014	2013	2012	2011	2010	2009	2008	2007	2006
R11										
R10										
R9										
R8										
R7										
R6										
R5										
R4										
R3										
R2										
R1										
Total	1	2	1	3	4					

Based on Table 3, one (1) respondent (R7) has nine (9) years of experienced in D&B projects using BIM since 2007. Meanwhile, R11 has six (6) years of experience involving in D&B project using BIM. In the meantime, five (5) respondents (R1, R2, R3, R5, and R10) have five (5) years of experience in D&B BIM project since 2011. Temporarily, three (3) respondents (R4, R8, and R9) started to involve in project using BIM since 2012. Only one (1) respondent (R10) has three (3) years of experience to involve in BIM since 2013.

From the results, it can be concluded that the BIM has started to be used since 2007. This is in line with research conducted by (Ahmad Latiffi et al., 2016) who reported the use of BIM started in 2007. Hence, in order to explore on the current process of using BIM in D&B project, it is important to identify the purposes of using BIM in D&B project, which are discussed in the next section.

Purposes of using Building Information Modelling (BIM) in Design and Build (D&B) Project

The purpose of this section is to explore how far the BIM is used in D&B project. Table 4 shows the purpose of using BIM in the construction project.

Table 4. BIM Uses in D&B Projects

Respondent	BIM Uses		
	Project Visualisation	**Improve Project Design**	**Detect Design Clashes**
R1	●	●	●
R2	●		●
R3	●		●
R4	●		●
R5	●		●
R6	●	●	●
R7	●	●	●
R8	●	●	●
R9	●	●	●
R10	●	●	●
R11	●		●
Total	11	6	11

Based on Table 4, there were three (3) purposes of using BIM in D&B project. The purposes were project visualisation, design review, and detect design clashes. From the table, all respondents have experienced using BIM for projects visualisation. BIM is used to help project client specifically to visualise a complete projects before the construction take place. Not limited to project client, BIM also helps other construction players such as architect and C&S to visualise and evaluate on the design produced effectively so that they could identify any discrepancies of design (Azhar, 2011; Eastman et al., 2011; Bryde et al., 2013).

Meanwhile, six (6) respondents (R1, R6, R7, R8, R9, and R10) experience using BIM to improve projects design. The respondents explained that the development of project design could be improved by using BIM software such as Revit Architecture and Revit Structural. Furthermore, the development of design into 3D model with project information could help to identify any discrepancies and conduct design analysis at an early phase. Added to that, BIM helps construction players to have a better design with less error by linking the design into 3D geometry with real time database (Eastman et al., 2011; Bryde et al., 2013; Dobelis, 2013; Ahmad Latiffi et al., 2014; Garber, 2014).

Moreover, all respondents were using BIM to detect design clashes. The respondents highlighted that most of the D&B BIM projects they involved were using BIM due to the capability of the concept in detecting design clashes. Clash detection is also known as a process in which used during coordination process to determine field conflicts by comparing 3D model of building systems (Eastman et al., 2011).

Therefore, from the BIM uses, the BIM process in D&B project could be identified. This is because the process of work is depending on the purpose of using BIM in project.

Next session discusses on the BIM process in D&B project.

Building Information Modelling (BIM) Process in Design and Build (D&B) Project

This section discussed on the current process of BIM in D&B projects. The purpose of this section is to provide information on how construction players use BIM in construction projects. The process is demonstrated based on the involvement of the respondents and BIM uses in D&B projects. Hence, the BIM process in D&B project is illustrated in Figure 3.

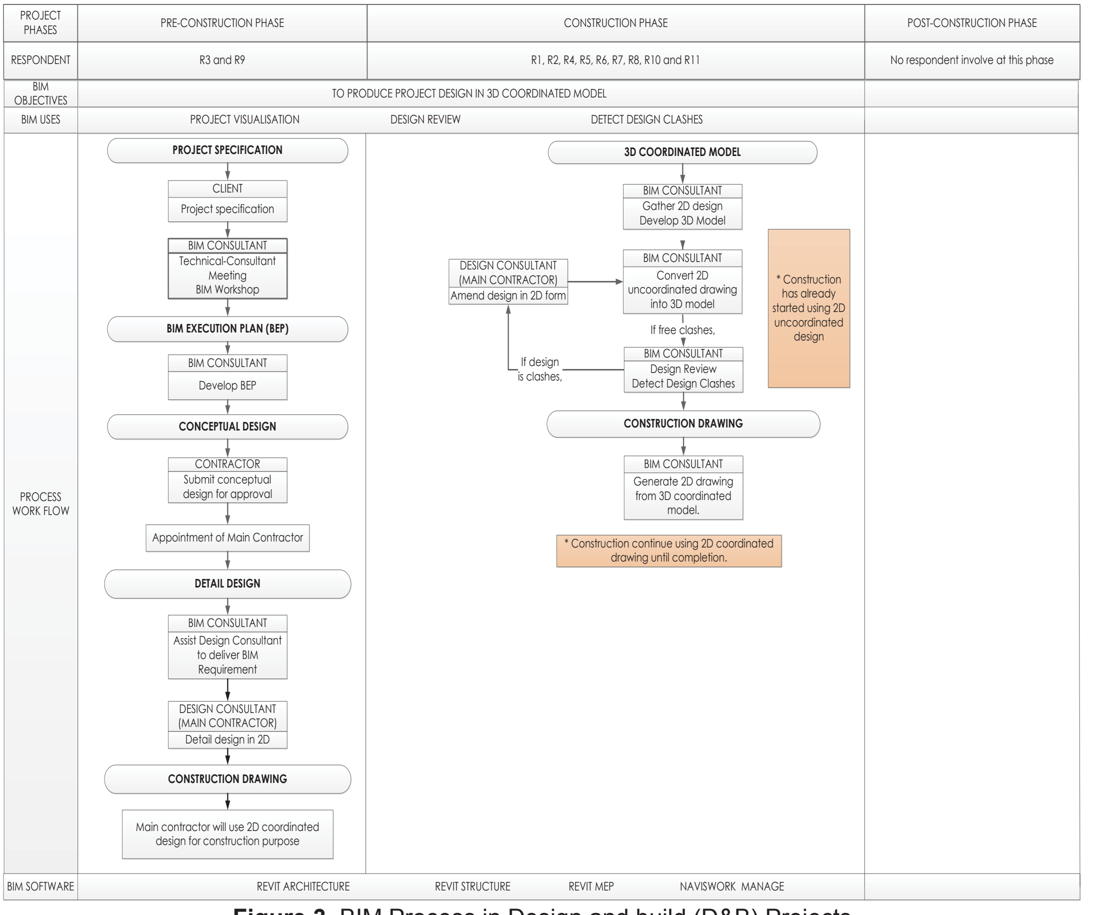

Figure 3. BIM Process in Design and build (D&B) Projects

The explanation of the figure is limited to the activities and process at pre-construction and construction phase. Hence, the explanation of the figure is categorised into two (2) phases as follows:

Pre-Construction Phase

The figure is consists of respondents involved, project phases, BIM objectives, BIM uses, BIM process and BIM software. From the figure, the involvement of R3 and R11 started only at pre-construction phase. The processes involved at pre-construction phase are identification of project specification, development of BIM Execution Plan (BEP), development of conceptual design and detail design. R3 has been appointed by project client as a BIM consultant for the project. Meanwhile, R11 acted as a project client. The party that initiate to use BIM will set BIM objectives and BIM uses for the project.

The process of BIM occurred by the appointment of BIM consultant under client to assist in identification of BIM objectives and its uses. (Kensek, 2014) mentioned that the first step of BIM implementation is to define the modelling and shared the process requirements for the project through the BIM uses. R3 stated that the appointment of BIM consultant by client was due to lack of knowledge and experience of client in using BIM in projects.

The objectives of using BIM in the project were to produce project design in 3D coordinated model and free from design clashes. From the objectives, BIM consultant will define BIM uses in more specific. Details of the objectives and uses will be stated in BEP. The implementation of BIM is normally lay down in BEP (Eadie et al., 2013; Kensek, 2014). BEP is a document to address an amount of information regarding responsibilities of construction players need to be contributed (Eadie et al., 2013; Kensek, 2014). Also, the BEP will be used as a supplementary agreement for the project.

Main contractor will start to develop conceptual design based on the requirement by the client. The conceptual design will be used to bidding the project. Only then, the client will appoint the main contractor for the project based on the conceptual design proposed by the main contractor.

At that point, by using client' specification, a detail design of the project will be executed by design consultant that fall under the main contractor. The respondents mentioned that the development of project' designed by design consultant was still in 2D due to the lack of capabilities of the design team in conquering BIM concept and BIM tools.

Construction Phase

Meanwhile, R1, R2, R4, R5, R6, R7, R8, R9, and R10 started to involve at construction phase. Those respondents were involved as architect, C&S engineer, contractor, and BIM consultant. The activities at construction phase were started by the development of 3D coordinated model and construction drawing. BIM consultant being appointed by main contractor will gather the 2D project design from design consultant under the main contractor. The purpose of collecting the 2D project design is to convert the design into 3D model.

The respondents stated that the purpose of developing 3D model must be referred to the BIM uses that are stated in the BEP. The development of 3D model must be a combination of information on 2D design (abstract of design concept) and 3D model (elaboration of design concept) (Eastman et al., 2011). After the development of 3D model, the project team including client could visualise the project as a whole before the completion (Forbes and Ahmed, 2010; Alaghbandrad et al., 2015).

The respondents mentioned that, BIM consultant used Revit Architecture and Revit Structure for converting 2D design into 3D model. Meanwhile, Naviswork Manage was used to conduct design analysis. Consequence to that, BIM consultant will get further information on project design from the design consultant. This is because the information on 2D design does not include sufficient information to fully describe 3D modelling. A BIM model must consists of sufficient information in order to conduct design analysis and other analysis such as site analysis, design performance, and energy analysis (Kim et al., 2016; Kokorus et al., 2016).

After the development of the 3D model, BIM consultant will conduct design review and detect design clashes. The purpose of design review was to improve the quality of design information as a whole rather than component (Azhar, 2011) and to detect any possible design issues. As mentioned by (Eastman et al., 2011), trade and system coordination is a critical process among contractor. Hence, BIM consultant will conduct design analysis to detect design clashes for addressing any design clashes between different trades which are architecture design and C&S design.

When design clashes is detected, BIM consultant will suggest for design amendment to the design consultant. The respondents explain that the amendment of design was made in the form of 2D document by a design consultant due to the lack of capabilities in using BIM software. Then, BIM consultant will conduct a design review and detect design clashes until the design is free from clash. Only then, the 2D project design will be generated for construction purpose.

However, the respondents also highlighted that the use of BIM started when the construction activities has already started using 2D uncoordinated project design. They also added that the use of BIM is more as a trial project. Consequently, improper planning and implementation of BIM among construction players made it difficult and failed to get the benefit of using BIM (Bryde et al., 2013). Furthermore, construction players are still trying their best way to implement BIM in a project in order to reap the benefit (Monteiro and Martins, 2012). In contrast, there were respondents who started to use BIM by developing a proper BIM objectives and BIM uses before the major construction take place.

CONCLUSION AND FURTHER WORKS

From the data collected, construction players have initiated the use of BIM in D&B projects. The purposes of using BIM are for project visualisation, to improve project design, and to detect design clashes. The implementations of BIM in D&B project were fulfilled at pre-construction and construction phase. Based on the BIM practices, the activities of BIM in D&B project is much similar with activities in conventional D&B project. The differences were by the activities done by BIM consultant in developing project design into 3D model for conducting design analysis.

The use of BIM software in managing project information is expected to improve the current practices of construction players in conventional project. Nevertheless, the process of developing project design still remains a traditional way which is in 2D document. This is due to the lack of capabilities of construction players in mastering the use of BIM software with the process involved. For that reason, a new designation related to BIM has been introduced and involved in the project to assist on BIM implementation, which is BIM consultant.

However, even there was an involvement of BIM consultant in the projects, the implementation of BIM by construction players were unable to reap the maximum benefit of BIM from the project. This is because the implementation of BIM only occurred when the construction has already take place. Nevertheless, proper planning and implementation of BIM at early phase of project could help them to get the benefit offered by BIM in improving construction project.

Further work will be focused on the potential improvement of BIM implementation that need for D&B projects. The improvement of the practices is vital to ensure that construction players could get BIM benefits, and thus the practices in construction could be improved.

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IMPACT OF BUILDING PERFORMANCE FAILURES TO THE OCCUPANTS' HEALTH AND SAFETY RISK: A LITERATURE REVIEW

Natasha Khalil[1] and Syahrul Nizam Kamaruzzaman[2]
[1]*Faculty of Architecture, Planning and Surveying, Universiti Teknologi MARA, Perak Branch, Seri Iskandar Campus, 32610 Seri Iskandar, Perak, Malaysia*
[2]*Faculty of Built Environment, Universiti Malaya, 50603 Kuala Lumpur, Malaysia*

Abstract
A building is a structure to provide humans with a comfortable working and living space and protect from the extremes of climate. However, buildings are also exposed to the various forces of change since the performance of buildings are not static over time. Issues in existing buildings such as space problems, poor design of emergency exits, inefficient energy use, air pollutions and ventilation discomfort are among the factors that may contribute to the failure of building performance. These malfunctions do not only affect the sustainability of buildings, but also the occupants who are also likely to be directly impacted by the building failure. Crucially, performance failure of a building also creates various risk issues and a direct impact to the building occupants in terms of health risk and safety risk. Health risk is related to exposure of building factors that may generate further health problems while safety risks, create a tendency upon injury, death, crime or nuisance. Hence, this paper explores the impact of building performance failure to the occupants' health and safety risks, in accordance to the performance elements and criteria. The review demonstrates that there is a plethora of risk factors with the potential to affect the occupants in different dimensions of building performance. The coverage of the social aspects, health risk and safety risk, are therefore potentially influenced by the failure of performance criteria.

Keywords: *Health and safety risk, Building performance evaluation, Performance failure, Health and safety impact, Building occupants*

INTRODUCTION

Existing buildings are considered to have key functions, as they generate the environment, human and economic resources. It is a durable fixed asset to carry potential activities and enabler to the core business. A proper assessment of its condition is important to prolong the building's lifecycle and ensure sustainability, as well as maintaining its aesthetic values. Apart from ensuring the safety of its inhabitants, the importance of maintaining and developing both the existing building stock and the already existing buildings is commonly recognised (Lützkendorf & Lorenz, 2006). Without a proper assessment, it may lead to building failure and may impart more problems such as failure in technical building elements, space inefficiency, poor safety aspects, environmental problems and noise pollution. These malfunctions do not only affect the sustainability of buildings, but also the occupants who are also likely to be directly impacted by the building failure. As highlighted by Druķis et al. (2017), existing buildings are designed according to the safety requirements of the decade they were built but in recent, hence the requirements of the respective safety level are higher. Therefore, awareness of the need to prioritise the comfort and safety of occupants is much concerned with the risk aspects perceived towards them. However, a number of methodological problems remain unsolved, as pointed out by Lützkendorf and Lorenz (2006):

- potential hazardous substances within the building require identification and assessment procedures
- determining an existing building's useful life span requires an appropriate assessment methodology

The above points concerning potential hazards that could lead to building performance failure need to be critically identified. The potential of hazard or risk identification can only be applied through proper assessment procedures, risk management and building performance assessment. The risk issues in building performance are not new, but until today, they have not been prioritized into building performance assessment as important aspects to address its occupants. Building occupants are likely to be affected by the performance of the building, and the building is also affected by the activities of its occupants (Olanrewaju et al., 2010). Therefore, in response to building performance aspects and requirements of occupants, the risk issues that need to be challenged in university building are delineated as follows:

a) *Operational Risks*: these are related to the processes within the organisation. As noted by Whitfield (2003), operational risks in buildings will potentially arise since the ability to anticipate and manage risks is critical to maintain on-going operations.
b) *Financial Risks*: these are related to the building's assets and safeguards. Failure in building performance includes a range of indicators, including energy and environmental management. For instance, Whitfield (2003) described financial risk in buildings as the potential loss of physical assets or financial resources that represent areas traditionally subjected to a more focused risk management.
c) *Reputational Risks*: they are correlated with the risk to maintain image and reputation of the building. A building's image may be tarnished when there is potential loss on performance failure.

Since risk is also associated with social factors such as crime and nuisance, it is vital to create a secure and safe environment so as to limit the risk in the existing buildings. Edwards (2000) suggested that the management and policing of buildings and spaces should complement design-based crime prevention measures. For instance, the common crime problems include theft from facilities, sexual offences, theft of vehicles, burglary in university buildings (Edwards, 2000; Said & Juanil, 2013; Whitfield, 2003). Edwards (2000) shows the importance of restricting entrance points and identifying crime hazards (Figure 1). This demonstrates that design can help define territories, as the buildings may be granted the ability to control spaces and limit movements and direct flows. Paralel to the design variables, design strategies such as breakaway systems or site selection able to reduce or eliminate the inherent risk from hazard damage, (Phillips et al., 2017). Therefore, the risk impact is not only derived from the poor performance of the building element itself, but also from other elements of design such as building orientation, building access, parking space, and entrance points.

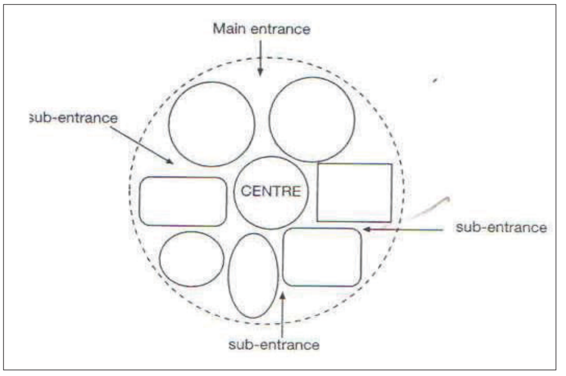

Figure 1. The Importance of Design Layout on Restricting Entrance for a University Building (source: Edwards, 2000)

As stated by Meacham (2010), the use of risk makes it possible to establish "tolerable" performance that is associated with what society finds tolerable with respect to various performance factors, and requirements for the improvement of design and construction of buildings. Hence, the definition and description of risk are given in the following section as an initial understanding of the term.

DEFINITION OF "RISK"

The interpretation of the term "risk" depends on how it is categorised (Almeida et al., 2010), whether in organizational contexts, management, business operations or social aspects. Nevhage and Lindahl (2008) suggested that perception in risk is the way stakeholders view a risk based on a set of values or concerns. Hence, in the context of the present research, risk is defined in the perspective of building management and the organizational perspective. According to Almeida et al. (2010), risk can be defined as "the effect of uncertainty (deviation from the expected either positive or negative)". It is much related to this study where risk is described as the perceived likelihood that the building occupants will receive negative impact due to poor building performance. Hence, risk can be perceived by describing risk factors and it can be associated with ordinary or small consequences. To develop a better understanding on the definition of risk, Table 1 summarises various definitions or descriptions of the term:

Table 1. Definition of Risk

AUTHOR (YEAR)	DEFINITION / DESCRIPTION
Abaza (2012)	The chance of an adverse event depending on the circumstances
Ahmed et al. (2007); Davidsson (2010)	Something that can be quantified by using probabilities
Cervone (2006)	A problem that has not yet happened
Hillson & Murray-Webster, 2004)	Uncertainty of such future events that might influence the achievement of one or more objectives such as the organisation's strategic, operational and financial objectives
Massingham (2010)	An unwanted event with negative consequences
Powers (2009)	A measure of the potential deviation of an outcome from its anticipated state
Richardson (2010)	The potential for loss or gain
Sinnha et al. (2004)	A function of the level of uncertainty and the impact of an event
Susilawati (2009)	The uncertainty of outcome, which may have a positive opportunity or a negative effect on project objectives

Although many different definitions of risk are being used in the field, nevertheless the main, underlying idea is similar; likelihood of occurrence. Despite commonly agreed definitions of the concept of risk, it is necessary to imply risk mitigation activities to direct and control an organization, with regard to risk. In the context of building operation, risk is associated with the failure of performance, as buildings must provide physical protection for their occupants and assets. This includes protection from crime, vandalism, terrorism, fire, accidents and environmental elements. Therefore, before incidents occur, risk must be mitigated in a proper approach as exemplified through a building performance assessment and risk is rationale to be associated with the building performance failure.

THE IMPORTANCE OF RISK IDENTIFICATION IN BUILDING PERFORMANCE EVALUATION (BPE)

Many studies (for example, Hwang et al., 2017; Camara et al., 2016; Lee & Hensen, 2015; Zalejska-Jonsson, 2012; Almeida et al., 2010; Lützkendorf & Lorenz, 2007, 2006; Lützkendorf & Speer, 2005; Meacham et al., 2005; Meacham, 2010; Thompson & Bank, 2007; Woods, 2008; Wolski et al., 2000) note that principles of building performance have been incorporated into sustainable buildings, by emphasizing the vulnerability of risk in building performance. Awareness of the need to prioritize the comfort and safety of occupants is much concerned with the risk aspects perceived towards them. This illustrates how aspects of allocating the susceptibility of risk have expanded more broadly into building performance. As stated by Thompson and Bank (2007), as buildings have become larger and house more people, political and societal issues have become more complex and risks associated with occupying buildings have changed. Even though risk is difficult to be removed or even to be reduced, it can be mitigated with proper management and a suitable approach. Building performance promises measureable expectations and if the promises are not achieved, adverse consequences are likely to lead to increased risks to occupants and tenants (Woods, 2008).The concept of incorporating risk into building performance evaluation (BPE) could be applied not only to mitigate the risk, but to reduce costs of operation, or to increase the level of productivity in a building.

Risks might only arise if attempts are made to realize a sustainable building by using inappropriate, experimental or untested construction products and technical buildings solutions (Lützkendorf & Lorenz, 2007). While the physical attributes of the built environment are the key to preparing for the risks associated with climate change, the way in which they are managed and used is an essential component of risk management. Buildings and infrastructure should be able to withstand environmental climate change while maintaining the comfort and safety of their occupants (White, 2004). The delineation needs to be updated to account for the ‘business-as-usual’ climate change scenario. Almeida et al. (2010) revealed that quality, performance, and risk approaches have the potential to improve end-user satisfaction as well as the potential for disclosing vital building-related information.

Cole (2000) noted that health risks to building occupants are normally a concern during construction, which emphasizes the significance of workplace safety regulations. However, in completed and occupied building, the vulnerability of building occupants to health risk should never be neglected. Typically, safety and security risk factors in buildings are associated with crime and vandalism, but risk could also be generated by poor building morphology, deterioration and poor design orientation. Several studies have shown that inefficiency of energy in buildings increases the vulnerability to risk in the safety and health of building occupants (Mostavi et al., 2017; Camara et al., 2016; Almeida et al., 2010; Altan, 2010; Cole, 2000; Lützkendorf & Lorenz, 2007, 2006; Meacham, 2010; Wolski et al., 2000; Zalejska-Jonsson, 2012). This suggests that prioritizing risk as the main constituent that could initiate a failure of other performance factors needs careful consideration. Altan (2010) found that heating and lighting requirements of vast estates, reliance on and heavy use of computers and research equipment have affected the comfort and health of building occupants. Thus, inappropriate provision of facilities in buildings can also prompt risk. Therefore, Table 2 summarised the risk frames that are constituted as social factors, can be categorized as follows:

Table 2. Categorization of Risk Frames

RISK FRAMES	DESCRIPTION
Health Risk	• Associated with human health effects; either direct or indirect exposure of building factors that can cause health risks. • Sick Building Syndrome (SBS), Indoor Air Quality (IAQ) and environmental quality is often related to the causes of health risks in buildings during occupancy period (Cole, 2000). • Building facilities (Altan, 2010) and post-construction activities such as demolition, salvage, maintenance, or renovation of structures have also been allied to human health impacts (Cole, 2000)
Safety/Security Risk	• Health and safety risk is consistently termed as having similar risk impacts • However, in a building's context, occupants' safety is regularly permitted in buildings during construction and post construction stage; injury, death • The tendency of safety risk is consistently associated with natural disasters, seismic building movement (B. J. Meacham, 2010; Meins, Wallbaum, Hardziewski, & Feige, 2010; Spence, 2004; Thompson & Bank, 2007), building defects, deterioration, building facilities, means of fire escape, (Meins et al., 2010; Wolski et al., 2000), etc. • The tendency on security risk : crime, theft, nuisance, burglary (Edwards, 2000)
Economic Risk	• The economy and related business environment risk is associated with the leaders and management of an organisation. • For example, the potential loss of physical assets or financial resources represents areas traditionally subjected to more focus as an economic risk (Whitfield, 2003) • Hence, businesses generally acquire insurance to protect against potential or unanticipated asset and/or financial losses
Environmental Risk	• Associated with the potential of failure or loss of building performance in meeting indoor and outdoor environmental factors, such as: • Visual comfort, thermal comfort, noise level, ecological building materials and ventilation comfort (Camilleri et al, 2001; Meins et al., 2010) • Flooding, storms or earthquakes (Lützkendorf & Lorenz, 2006)
Comfort Risk	• Comfort aspects often related to the needs of occupants and regularly derived from holistic building aspects. • Failure to meet occupants' comfort, creates risk that could lead to other risk aspects such as health and safety risk (Meins et al., 2010) • Comfort risk may include environmental performance factors, visual comfort, thermal comfort, noise level, ecological building materials and ventilation comfort (Meins et al., 2010), building quality (Almeida et al., 2010; Meacham et al., 2005; Meacham, 2010)
Political Risk	• Similar to economic risk in that it is likely to be associated with business activities and resources; political risk is thoroughly allied to image and reputational risks. • Reputation lies in the business organization and is guarded only by the policies and decisions made; wrong decisions may tarnish reputation by failure to effectively manage reputational risks (Whitfield, 2003)

Within this understanding of risk frames, it can be seen that the principles in risk is firstly to minimize the impact of building performance, and then control for the health, safety and well-being of the building occupants (Woods, 2008). It therefore benefits the building occupants who are most severely impacted by the occurrence of risk, as the operational activities in the building are continuous and are not undertaken only within a specified duration. In the context of relating the risk impact to the occupants, hence the risk frames are focused on health risks and safety risks. An explanation of both risk frames is given below:

Health Risk

Since the concept of evaluation for building performance is conducted during occupancy or during post construction, human health issues are given greater coverage than other environmental issues. The prevalence of risk associated towards human's health includes indoor air quality (Cole, 2000), climate change (Dyer & Andrews, 2012), and inefficient energy (Altan, 2010). The risk is highly associated with human's health includes thermal stress, and vector-borne diseases (Dyer & Andrews, 2012). According to Ho et al., (2008), building should minimizes the physical and mental health risk of its occupants, such as safeguarding against infectious diseases or mental illnesses found within the built environment.

Safety Risk

The creation of a secure and safe environment is essential for the efficient functioning of a all kind of buildings (Edwards, 2000). Crime, for instance, is costly to an organisation in a number of ways. The loss may include the replacement of equipment, the repair of buildings, and the additional cost for a surveillance service provider or security systems. Apart from crime, nuisance is also related to safety aspects that are a matter of concern for the building occupants. For this research, the context of safety is also extended to human injury that may have consequences for short or long term suffering. Apart from injuries, the worst part of safety risk could lead to death.

METHODOLOGY

This paper discusses an in-depth and comprehensive literature review relating to performance issues in existing and occupied buildings, and the consequences of building failure to the occupants' risk. It also reviews on the suitability of indicators in building performance assessment as the predictor variables that may impact the building occupants in terms of health and safety risks. The review of previous building performance assessment schemes was also included in this paper. Eight (8) schemes in building performance were reviewed; Building Quality Assessment (BQA), Malaysia's Green Building Index (GBI), Building Health and Hygiene Index (BHHI), Building Safety Condition Index (BSCI), Building Environmental Assessment Method (HK-BEAM), Total Building Performance (TBP), Comprehensive Assessment System for Built Environment Efficiency (CASBEE) and Comprehensive Environmental Performance Assessment Scheme (CEPAS). The review of the schemes is needed to initially capture the indicators, known as performance-risk indicators (PRI) as the predictor variables that may be allied to occupants' risk. From the initial list of PRI, a further review on the impact was described in order to show how the possible failure of each indicator impacted the user's health and safety risk.

LITERATURE REVIEW: PERFORMANCE ISSUES AND INDICATORS RELATING TO HEALTH AND SAFETY RISK

Literatures by Lützkendorf and Lorenz (2007), as well as Preiser (2005), showed that the mandates or the criteria in building performance depend on the objectives of evaluation, which includes, functional performance (functionality, applicability, adaptability), indoor environmental performance (energy use, materials use) and technical performance. Analytical review of previous building performance assessment schemes, involving eight (8) schemes, found that the primary concepts of the previous tools are similar in several aspects. Discrepancies between the tools are generally linked to the approach taken towards the evaluation and the building occupants: whether the assessment is regarded as a matter of serious concern or it is likely to be ignored. Table 3 provides a detailed summary of the performance indicators, with several items and sub-items that relate to established assessment tools.

Table 3. Major findings in literature on the elements and indicators in previous schemes/tools

BUILDING PERFORMANCE TOOL	PARAMETERS / ELEMENTS / INDICATORS																
	Access and circulation	Acoustic comfort	Adaptability / Integrity	Amenities	Cleanliness/ Hygiene	Emergency Exits	Energy	Environmental conditions	Health and safety	Indoor air quality	Materials	Management	Services (electrical, fire, mechanical, IT)	Space functionality	Structural	Thermal performance	Visual performance
BQA	✓			✓				✓	✓			✓	✓	✓	✓		
TBP	✓		✓					✓						✓		✓	✓
CASBEE		✓	✓				✓			✓	✓					✓	✓
BHHI		✓			✓	✓		✓		✓	✓	✓	✓			✓	✓
BSCI	✓	✓			✓	✓		✓		✓	✓	✓	✓		✓	✓	✓
HK-BEAM		✓		✓	✓	✓			✓		✓	✓	✓			✓	✓
CEPAS				✓	✓		✓	✓	✓		✓	✓					
GBI		✓					✓	✓		✓		✓	✓				✓

According to Lützkendorf and Lorenz (2006), the application of many existing assessment tools does not provide the building stakeholders with appropriate information on the impacts of their decisions on the building occupants' health and well-being. It has been debated that there is a possibility of risk that could jeopardise the occupants caused by the failure of building performance aspects. As an example, McDougall, Kelly, Hinks, & Bititci (2002) pointed out that the BQA is silent on the intrinsic quality of the items that are being assessed and therefore, the results could be quite misleading. Baird (2009) also argued that

CASBEE tends to focus more on the technical aspects such as green building aspects, energy consumption, water use or materials. The argument is raised due to the actual performance in operation that can severely compromise the specification and technical performance that may fail to take into account the occupants' needs. Even though safety is typically related to risk and it is addressed in BQA, in general, there is an absence of indicators to establish the risk basis for occupants and how risk relates to all other performance indicators. As mentioned by Woods (2008), under this more comprehensive definition of measurable building performance, an owner needs to assess what indicators of the building affect the primary business function. In meeting the current changing needs in a building, performance is not restricted only to energy. It should also address the probability of risk occurrence from the elements and indicators of building performance. Hence, it is crucial to identify possible indicators for this study instead of using the listed criteria from the existing rating systems. Unfortunately, many stakeholders could not identify risk as the main susceptibility that could trigger the failure of a building's function. As a consequence, it may affect the whole performance of a building if it is not addressed in the early stage of building development.

Therefore, from the literature findings of the performance elements, an initial list of indicators relating to the health and safety risks are compiled as to justify the rationale of each indicator to the occupants' risk. The indicators are known as predictor variables that may constitute health and safety risks to the building occupants. Figure 2 depicts 18 indicators, known as Performance-Risk Indicators (PRI), related to the performance element that may be linked to occupants' risk. The list of indicators is drawn based on the analytical review of eight (8) building performance assessment schemes.

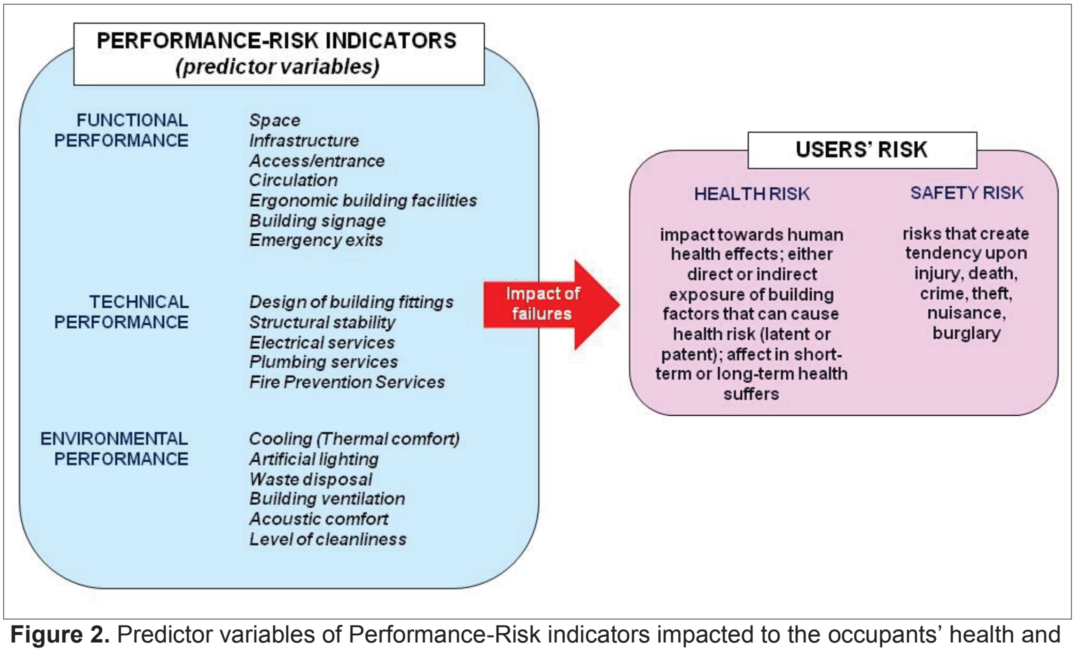

Figure 2. Predictor variables of Performance-Risk indicators impacted to the occupants' health and safety risk

The listed indicators shown in Figure 2 are the predictor variables that can contribute to performance level and to occupants' health and safety risks. In general, the list covers the overall aspect of performance indicators that mainly concern the risk criteria and their impact on the occupants. The coverage of the social aspects, health risk and safety risks are influenced by the listed indicators. To substantiate the impact of each indicator relating to the occupants' health and safety risks, the following discussion of findings provides a detailed explanation of the PRI in terms of performance issues in regard to the impact on building occupants.

THE IMPACT OF PERFORMANCE FAILURES TO THE OCCUPANTS' HEALTH AND SAFETY RISK

Descriptions are provided for each of the indicators to better understand the context of this study by addressing the performance issues for each indicator to elucidate the impact of the indicator's performance on occupants' health and safety risks. As depicted in Figure 2, there are 18 indicators or PRI that were listed as predictor variables; *spaces, infrastructure, access, circulation, ergonomic of building facilities, signage, emergency exits, design of fittings, structural stability, electrical services, plumbing services, fire services, thermal comfort, visual comfort, waste disposal, ventilation, acoustic comfort* and *cleanliness*. Hence, the description and the impact of each PRI to the occupants' health and safety risk were analysed as follows:

Spaces

Space is defined as an area, room or surface that is available for use, operation and activities. It is understood that certain spaces in any facility are significantly important to the overall facility performance (Pati et al., 2006). Hence, for this research context, the space aspect was the measured area as allocated in the plan. Generally, the space issues in building performance are addressed on the improper or inadequate size, density problems, and spatial deficiencies in the buildings (Ibem et al., 2013). As stated by Pati et al. (2006), such spaces with high-importance determine to a large extent how the facilities perform as a whole in a particular building; for example: educational building, courtrooms, or hospitals. Ideally, an improved use of spaces reduces the risk and the perception of risk for occupants as well-planned spatial relationships may improve profit and productivity. The space issues relating to occupants' comfort and health was also revealed by Low et al. (2008). He stated that the arrangement of a space can affect a person's performance directly, thus will affect the quality and quantity of their work. Improper space may disrupts the phycshological wellbeing (health issues) and disruption of safety provision to occupants (crime, nuisance). Thus, space becomes an important trigger to affect human's helath and safety.

Infrastructure

Infrastructure is defined as the basic physical and organisational structures and facilities needed for any area development. Ideally, the infrastructure comprises of vehicle parking, landscape, walkway and pedestrian areas (Edwards, 2000). Generally, the aspects are concerned with occupants' safety due to crime cases when the provision of infrastructure is neglected. For instance, research on space efficiency by the Space Management Group (2006) for UK's higher education building projects revealed that parking problems were the only serious complaint made by the occupants. BQA tools described that the shape of parking areas makes finding them difficult and are often poorly located. Hence, it may encourage crime, nuisance or car stealing that will inevitable affect the occupants' health (psychology and traumatic factors) and safety (physical and social factors).

Access/entrance

In general, any building requires an access or entrance that allows the occupants to enter the enclosed building area. It is described as the point that the occupants may go into a building or enclosed area. The building should be designed to be easily accessible by occupants and visitors. Lack of surveillance, or hidden entrances, may increase opportunities for crime, as mentioned by Edwards (2000). Building designs must recognise the importance of restricting entrance points and identifying territories early in the development of the building masterplan (Edwards, 2000). Hence, considerations for this aspect include ease of locating the building and clearly visible entrances to the building. As similar to other functional variables, improper design and location of building access may prone towards crime or nuisance and affected the occupants' psychology health and physical safety.

Circulation area

In the context of this research, circulation area is extended to the provision or allocation of corridors, lobbies and staircases. A stairwell enclosure is a term used to mean the area occupied by stairs and landings and any part of a horizontal circulation area not separated from them by doors (Hassanain, 2007). Vertical segregation in the circulation area in campus buildings can become alienating and sometimes dangerous (Edwards, 2000). In a study of fire safety in university students' housing by Hassanain (2008), it is found that common violations in stairwell enclosures included stairwell enclosures that were not fire-rated, broken closers and latches and doors propped open. Such conditions may facilitate the spread of smoke and toxic gases to other floors in the building, as well as preventing the residents from using the stairwell to escape from fire (Hassanain, 2008; Zamani et al., 2013).

Ergonomic building facilities

It is defined as the relation between the design of facilities fit to be used by the occupants (for example: working table, chairs). Ergonomic hazards refer to workplace conditions that pose the risk of injury to the musculoskeletal system of the worker. According to Badayai (2012), functional comfort refers to the ergonomic support for occupants' performance of activities. Hence, ergonomic furniture or facility size might help to ensure functional comfort. When functional comfort is not achieved, the building occupants may have a tendency to suffer health problems, such as back pain, body injury or muscular disorders. Previous research has revealed that ergonomic comfort is related to functional requirements in a building; that includes building facilities (Elearn, 2009; Loftness, Lam, & Hartkopf, 2005). As a summary, health risk may arise from unsuitable facilities or furniture used by the building occupants.

Building Signage

Signage is defined as an identification or direction used to show information about something. To simplify, signage is generally located indoors and outdoors as a system to direct occupants for better way-findings. Improper allocation or poor signage in a building will have a negative effect on building occupants (Riley et al., 2010). Any hazards should be identified, highlighted and described using clear building signage. According to Bordass (2003), assessment of building performance can be used to identify and remediate such problems associated with poor signage and lack of storage. It is also supported from precedent research proper signages indicates the performance level of building and occupants' wayfinding (Elearn, 2009; Yau, 2006). Providing better interior signage and colour coding are needed to assist people unfamiliar with the space and for better way-finding expecially during safety evacuation, thus reduce safety hazards to the occupants.

Emergency Exits

An emergency exit is a mandatory requirement for any building as a fire prevention requirement and for the building to be certified as fit for occupation. It is a structure or an area that is allocated in a building for faster evacuation, especially in the event of fire. Safety and security measures relating to people are being given greater attention due to increasing awareness among the population; therefore suitable hazard prevention or escape routes and emergency exits need to be considered (Meins et al., 2010). As revealed in the previous study by Yau (2006), visibility of emergency exits with supplemental emergency lighting may help building occupants evacuate in case of an emergency. Thus, it helps to reduce safety hazards to the occupants, and consequently helps to save their life (related to health risk).

Design of building fittings

This indicator deals with the design of the openings that includes doors, windows, ironmongery, door fittings and window glasses (Goh & Ahmad, 2012). Damaged windows will leave the occupiers unprotected from burglars, rapists and other criminals. It will contribute to the reducation safety hazards to the occupants. Faulty windows could allow the entry of dangerous insects like mosquitoes into the building which can cause dengue fever (Olanrewaju et al., 2010), that may affect the occupants' health to disease exposure.

Structural stability

Structural items include the structural parts of building such as columns, beams, floor slabs, concrete walls or roof slabs. According to Ali et al., (2010), the structural stability of a building must be inspected and maintained from time to time in order to ensure the occupants' safety. Hazards in the built environment have been closely related to accidents occurring in buildings; thus, occupants must be safeguarded against hazards arising from structural failure. Previous findings by Olanrewaju et al., (2010) have also revealed that defective roofing and its structure may cause psychological effect to the occupants, thus affect their health and safety.

Electrical services

Electrical services deal with the functioning of power that is used to provide light, to heat buildings, or to power devices. Faulty electrical systems are a very serious defect as they can lead to death. In their research, Olanrewaju et al., (2010) revealed that the urgency of identifying defects in university buildings is needed because faulty electrical equipment has been rated as the second most frequently rated defects. The findings also showed that user safety and user well-being are of paramount consideration due to faulty electrical services.

Plumbing services

In general, plumbing services refers to the functioning of piping; arrangements of pipes, fixtures, fittings, valves, and traps in a building which supplies water and removes liquid-borne wastes. Corrosion and leaking which are due to improper installation or aged plumbing and drainage systems in buildings involve a higher remedial cost (Wong, 2002). Performance failure in plumbing systems (corrosion or leaking) can lead to more serious defects, thus affecting the safety of the building occupants. Optimisation of access to the plumbing equipment for inspections and maintenance could help to mitigate these risks (Dewlaney & Hallowell, 2012). Olanrewaju et al., (2010) highlighted that clogged of pipes could be very disruptive and cause offensive odour, as it may lead to health consequences to the building occupants.

Fire Prevention Services

Fire prevention services are a mandatory system installed in buildings to reduce fire emergency and damages such as allocation of smoke detectors, sprinklers, fire extinguishers, and hose reels. Improper installation and poorly maintained or dysfunctional fire fighting systems create safety risks to the building occupants. Hassanain (2008) suggested that frequent maintenance of fire protection and safety equipment is needed to improve the level of safety and to mitigate risks in occupied buildings. It is also supported from precedent research proper signages indicates the performance level of building and occupants' wayfinding (Elearn, 2009; Yau, 2006).

Cooling (Thermal comfort)

For the purpose of this study, it is generally concerned with the level of air cooling. Air cooling is a standard method of cooling used to dissipate heat. Olanrewaju et al. (2010) described that faulty air conditioning systems could lead to discomfort, growth of mould leading to the sick building syndrome, pathogenic diseases and also facilitate water seepage. Poor performance of thermal comfort can have serious consequences for occupants' health and safety. Thermal comfort study findings by Kavgic, Mumovic, Stevanovic and Young, (2008) have revealed that 63% of building occupants claimed that they suffered most prevalent symptoms related to nasal and respiratory organs, dry or watering eyes, and headaches.

Artificial lighting (Visual comfort)

Visual comfort is a subjective condition of visual well-being induced by the visual environment (Frontczak & Wargocki, 2011). For this study, artificial lighting is generally concerned with the adequacy and the level of lighting for the electric lightings system. Issues affecting building occupants due to artificial lighting in buildings are often related to the adequacy, control and level of brightness. A study by Hassanain (2007) revealed that students of King Fahd University in Saudi Arabia were dissatisfied with the adequacy of artificial lighting at study areas and the lighting control levels in the room. Heerwagen (2000) reported that glare from electric lighting is associated with headaches, muscular skeletal problems, and eyestrain. According to the Canadian Centre for Occupational Health & Safety (2013), poor lighting can be a safety hazard resulting in misjudgements about the position, shape or speed of an object, which can lead to accidents and injury. It can also cause health hazards: too much or too little light strains the eyes and may cause eye discomfort (or burning) and headaches. As revealed from the previous research , the occupants are suffering health issues due to distress, glare levels and insufficient illumination levels (Low et al., 2008).

Waste disposal

It refers to the practices and management of general and solid waste within buildings. The type of solid waste can be categorised as organic, paper, plastic, glass, metals, and others (textiles, leather, rubber, multi-laminates, e-waste, appliances, ash, other inert material).Waste is considered as one of the environmental concerns (Kowaltowski et al., 2006). Improper disposal of waste or poor management of waste can lead to leakage of hazardous substances and indoor air pollution, as emphasized by Wang et al. (2005). Thus, it can cause health problems among the building's occupants such as respiratory problems and other effects, as contaminants are absorbed from the lungs into other parts of the body.

Building ventilation

It is defined as the circulation of air throughout a building that removes air either naturally (windows) and/or mechanically. Inadequate ventilation in a building leads to the sick building syndrome (Zamani et al., 2013), thus affecting air quality and consequently the health of occupants. Hassanain (2007) suggested that poor air quality in an occupied building could affect the occupants' health, resulting in higher rates of absenteeism and lower productivity. Pollutants such as odors and dust due to poor ventilation and indoor air quality may cause discomfort and health consequences (Badayai, 2012).

Acoustic comfort

As defined by Low et al., (2008), acoustic concerns relate to noise and vibration and the performance refers to how well noise is being managed in a space. Noise is sound that is unwanted in one context and is annoying to the unwilling hearer. This aspect of the limits of acceptability aims to ensure the physical health and safety of building occupants. The built environment needs to be free from excessive noise so as to protect the occupants from potential hearing damage (Low et al., 2008). It is also revealed from precedent research that lower levels of noise that are not physically dangerous are able to distract people from their work and is an additional stressor (Badayai, 2012).

Levels of cleanliness

It refers to a scale of cleanliness level that ensures the building is free from dirt and dust, and is related to hygiene and disease prevention. The level of cleanliness in buildings is often related to the impact of indoor air quality (Frontczak & Wargocki, 2011; Kavgic et al, 2008). Previous research also shows that building cleanliness leads to a health environment, provide better air quality and odour (Kavgic et al., 2008; Mahbob et al., 2011). The causes of unhealthy environment from improper waste management may derive from many factors such as improper waste disposal, moisture or dirt on heating-ventilation systems and contaminants from building materials. The consequences for occupants' health include respiratory health effects and other severe effects such as rashes, eye irritation, and headaches.

The above review highlights that health and safety risks to the occupants may be influenced by a profusion of building factors which interact in the different extent of a building performance. This review explores and contributes to how risk identification can help to enhance building performance through linkages with performance optimisation for the comfort and satisfaction of building occupants. Hence, the next step for risk analysis and risk transfer could be planned as a holistic risk management process in building performance evaluation.

CONCLUSION

As a conclusion, building performance and risk management is an emerging field of academic inquiry. It integrates elements from two broader fields; building performance and risk management, that are previously separated and self-contained in terms of both concepts and principles. This review will contribute to the body of knowledge by providing a holistic view of indicators that affected the occupants' health and safety and the potential impact as further consequences. It was revealed that the identification of risk in the risk management process can help to optimize building performance, which has a direct impact on building occupants' comfort and satisfaction. It would thus help to provide opportunities for the improvement of building performance and highlight the relationships with occupants' risk and satisfaction. This review recommends the necessity of building performance rating tool to incorporate the social aspects (occupants' risk) in the building performance evaluation (BPE) that are currently lacking. The building risk-performance rating tool is informative to the industry practitioners (building owners, designers' team, maintenance providers) to customize the list of indicators as risk identification during the assessment of building performance. Hence, it shall provide a significant contribution to the industry in determining performance deterioration and possible impact of failure, thus able to allocate strategy for mitigation measures.

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SEISMIC PERFORMANCE OF TWO-BAY TWO-STOREY RC FRAME UNDER IN-PLANE LATERAL CYCLIC LOADING

Nor Hayati Abdul Hamid[1], Anis Azmi[1], Mohd Irwan Adiyanto[2] and Mazlina Mohamad[3]
[1]Institute Infrastructure Engineering and Sustainable Management (IIESM), Level 3, Block 1, Engineering Complex, Universiti Teknologi MARA, Shah Alam, 40450 Selangor, Malaysia
[2]Faculty of Civil and Natural Resources, Lebuhraya Tun razak, 26300 Gambang, Kuantan, Pahang
[3]Faculty of Civil Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor

Abstract
The main purpose of this paper is to evaluate the seismic performance of double bay two-storey reinforced concrete frame under in-plane lateral cyclic loading which were designed using EUROCODE 8 by take into consideration of seismic loading. A one-half scale prototype model of RC moment resisting frame was constructed in heavy structural laboratory and tested under in-plane lateral cyclic loading starting from ±0.1%, ±0.2%, ±0.25%, ±0.5%, ±0.75%, ±1.0%, ±1.25% up to ±3.0% drift with increment of ±0.25%. Seismic performance of the RC frame is evaluated in terms of hysteresis loop, stiffness, ductility, lateral strength, stress-strain relationship and equivalent viscous damping. Visual observation of the crack pattern after testing were observed where the beam- column joint suffered the most severe damage as it is the critical part in moment resisting frame. Cracks of concrete started to occur at ±2.0% drift and become worse at ±2.5% drift. The experimental result shows that the maximum lateral strength of specimen is 99.98 kN and ductility of specimen is μ=4.07 which lies between $3 \leq \mu \leq 6$ in order to withstand the earthquake ranging from moderate to severe conditions.

Keywords: *Reinforced Concrete Frame, Hysteresis Loops, Lateral Strength Capacity, Ductility, Stiffness, Equivalent Viscous Damping*

INTRODUCTION

Modern seismic design codes of practice have been incorporated the new requirements for designing reinforced concrete structures by taking into account the seismic load with sufficient ductility. There are a lot of structural damages and partial collapse of buildings caused by earthquakes due to in adequate anchorage bar in beams, insufficient longitudinal reinforcement in the columns, lack of diagonal bars in beam-column joint and use of plain round bars as longitudinal reinforcement (Ghalli, 2006). In high seismic region, it is essential to follow a specific seismic code of practice to ensure the safety of buildings. But for low or moderate seismic regions such as Singapore, West and East Malaysia, the moment resisting RC frames are still design using BS8110 where there is no provision for earthquake load at all. A few experimental works had been conducted using tunnel form building (Hamid et al., 2014a; Anuar et al., 2014a; Anuar and Hamid, 2014; Hamid et al., 2014b; Tukiar et al., 2014; Anuar et al., 2014b and Ghani et al., 2013), research on non-seismic precast reinforced concrete beam-column joints (Ghani et al., 2013; Kay Dora and Hamid, 2012; Hamid, 2010), studies on wall-slab joints of Industrialized Building System (IBS) (Hamid and Masrom, 2012; Al-Aghbari et al., 2012) and specific study on precast shear-key wall panel which designed according to BS8110 (Hamid and Mohamed, 2013). The experimental results showed that these structural components performed poorly under in-plane and out-of-plane loading due to low ductility. Therefore, in order to reduce the damages and collapses of the RC buildings, the seismic code of practice should be adopted especially in Sabah, East Malaysia which was categorized as moderate seismic region. The

2015 Ranau Earthquake with magnitude of 6.3 scale Richter caused severe damages to the teachers' quarters and hospitals' quarters in Ranau. Most of these buildings were designed using BS8110 by using minimum percentage of reinforcement bars in columns and beams. Reinforced concrete frame is one of the important elements in RC structural components which most of buildings in Malaysia are commonly designed with relatively weak column and strong beam. In order to sustain earthquake loading, RC frames should have enough ductility with high ductile in beam-column joint. It is the most critical part in RC frame and more vulnerable to have worse deterioration when subjected to lateral load where it is the part of transferring gravity and lateral loads. Thus, this study is purposely to evaluate the seismic performance of a moment resisting frame which designed using EC8.

DESIGN OF RC FRAME

Figure 1 shows the isometric view and dimension of one-half scale prototype RC moment resisting frame which had been constructed on the foundation beam with dimension of 5450×1800×300 mm. The height of every floor is 1650 mm with the size of column is 200×200 mm. The top level of RC frame was constructed with slab of thickness 200 mm while first floor level is just a bare frame. Figure 2 shows two-bay two-storey moment resisting RC frame had been constructed on strong floor at Heavy Structural Laboratory, Faculty of Civil Engineering, Universiti Teknologi MARA, Shah Alam. This specimen was ready for the experimental testing under in-plane lateral cyclic loading using displacement control method with different drifts of loading regime. The moment resisting frame was painted with white colour water based for easily marking of percentage drifts and hairline cracks.

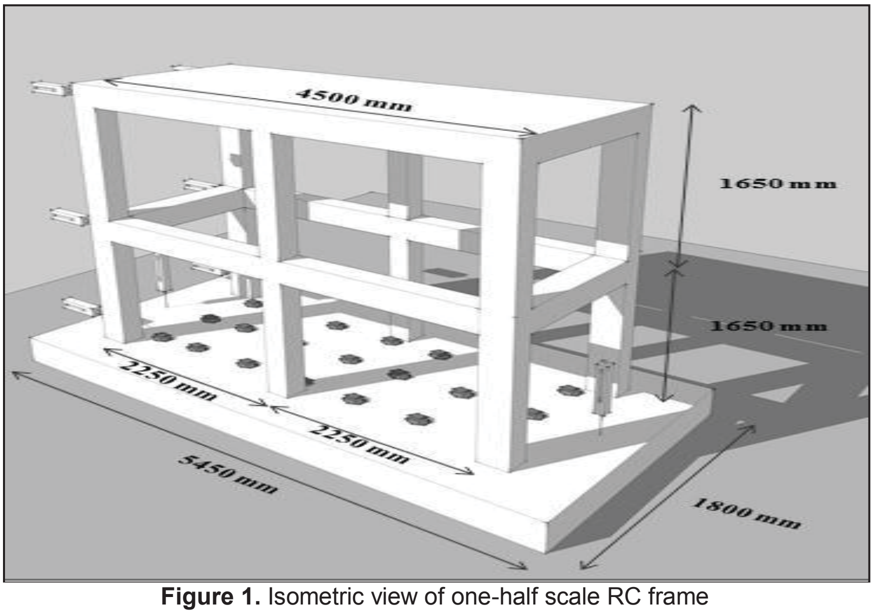


Figure 1. Isometric view of one-half scale RC frame

Figure 2. The two-bay two-storey moment resisting RC frame

EXPERIMENTAL SET-UP

The prototype model of double-bay two-storey reinforced concrete frame was tested under in-plane cyclic loading where the foundation beam was bolted to the strong floor. A double actuator with 500kN capacity load cell was attached to reaction frame and nine numbers of linear potentiometers (LVDTs) were used to measure lateral displacement of specimen as shown in Figure 3. LVDTs were installed at critical region of RC frame where the maximum displacement and potential crack are expected to occur such as at beam-column joint and foundation beam to monitor the movement and uplift of the specimen.

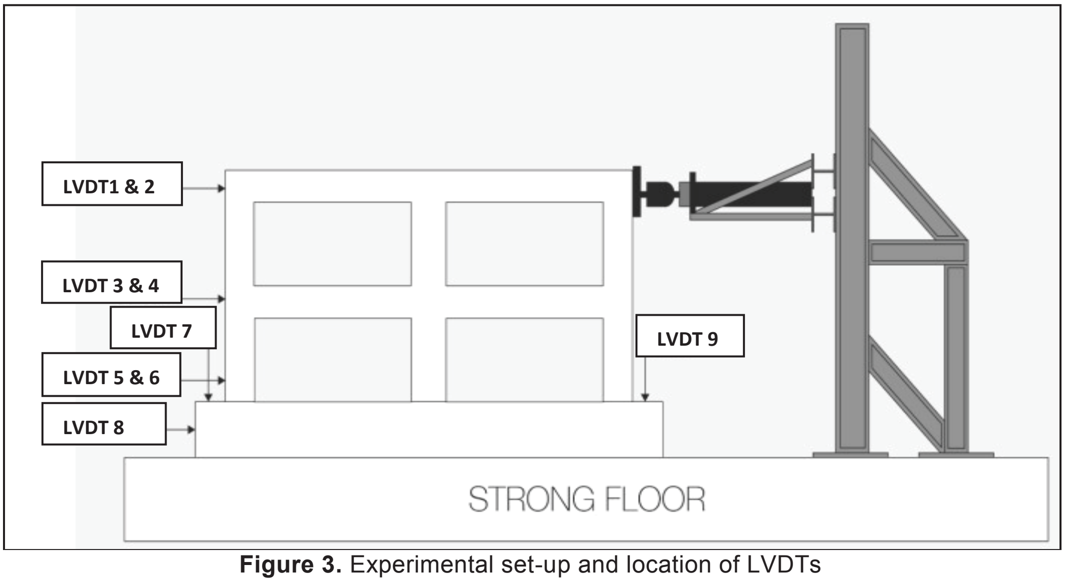


Figure 3. Experimental set-up and location of LVDTs

The specimen was tested using displacement control method starting from drift ±0.2%, ±0.25%, ±0.5%, ±0.75%, ±1.0%, ±1.25%, ±1.5%, ±2.0%, ±2.25%, ±2.5%, ±2.75% and ±3.0% drift. Two cycles of loading were tested for each drift which consist of pushing and pulling direction. Figure 4 shows the loading regime for RC frame comprises of 26 successive cycles tested under in-plane lateral cyclic loading. Figure 5 shows the detailing of one corner beam-column joint of RC frame. The size of the column is 200x200 mm and the beam size is 200x250 mm. The spacing between the shear reinforcement bars is 60 mm, diameter for main bar is 16 mm for beam, 12 mm diameter for the column and 10 mm diameter for the stir-up.

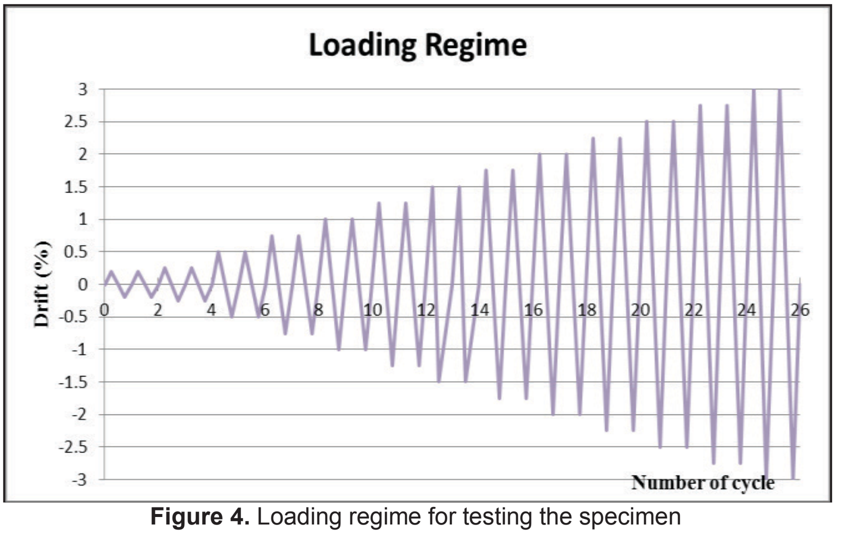


Figure 4. Loading regime for testing the specimen

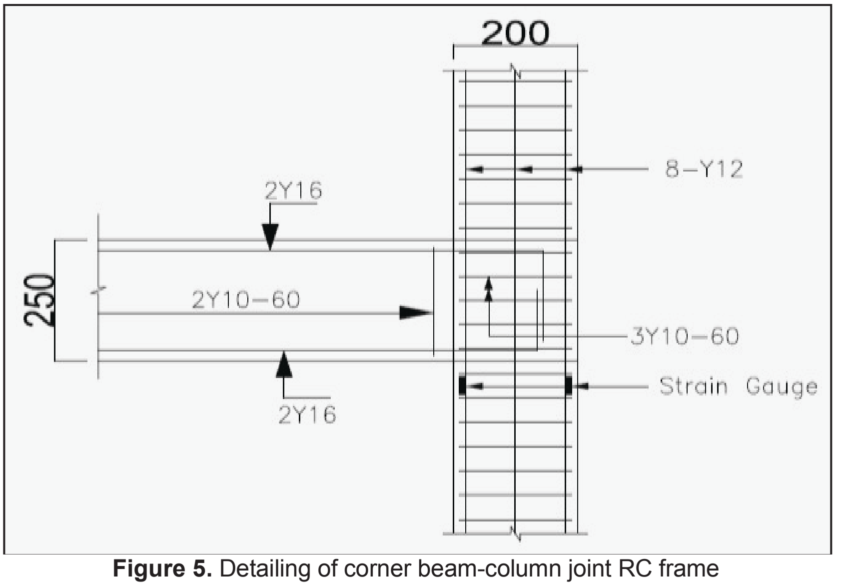


Figure 5. Detailing of corner beam-column joint RC frame

RESULTS AND DISCUSSIONS

Visual Observation

Crack pattern is very important to recognize the response of the structure under several loading and also to identify mode of failures. Visual observation of the cracks at the main components of the structure such as column, beam and beam-column joint were captured and recorded. Several types of crack were observed which are shear crack, hairline crack, diagonal crack, horizontal crack and vertical crack. Based on the visual observation, no cracks appear during the first four cycles when subjected to initial drifts of ±0.2% and ±0.25%. Initial cracks were observed at RC frame subjected to ±0.5% drift which the first hairline crack visible at column base and beam-column joint. At ±0.75% drift, vertical crack at beam and shear crack at beam-column joint were started to appear. From the visual observation, most of the cracking occurred in pushing direction of the tension zone. Figure 6 shows the joint that had undergone severe damages at ±1.75% drift. The crack became wider until it caused large spalling of concrete at bottom left corner of the beam-column joint. At ±1.75% drift, large shear cracks started to occur at the corner beam-column joint and caused disintegration of concrete. Structural performance of corner joint is significantly influenced by diagonal shear crack and rotation of large beam end resulted with large crack opening that speed up crushing of concrete at the face of joint (Tukiar et al., 2014).

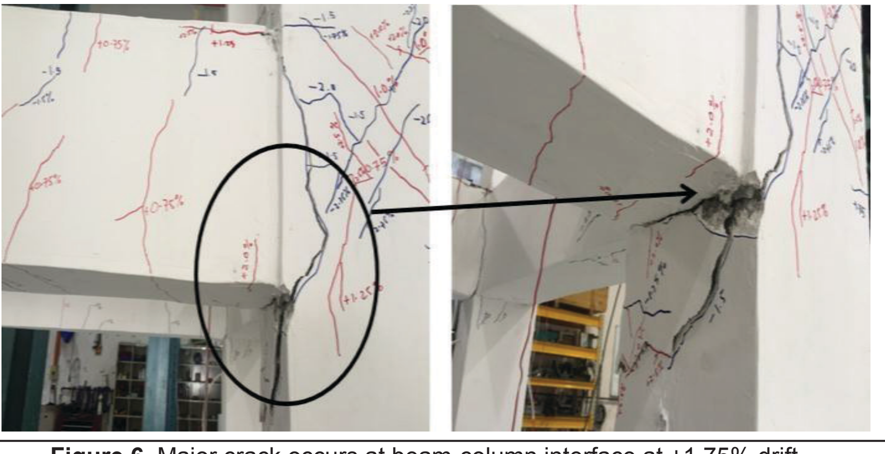
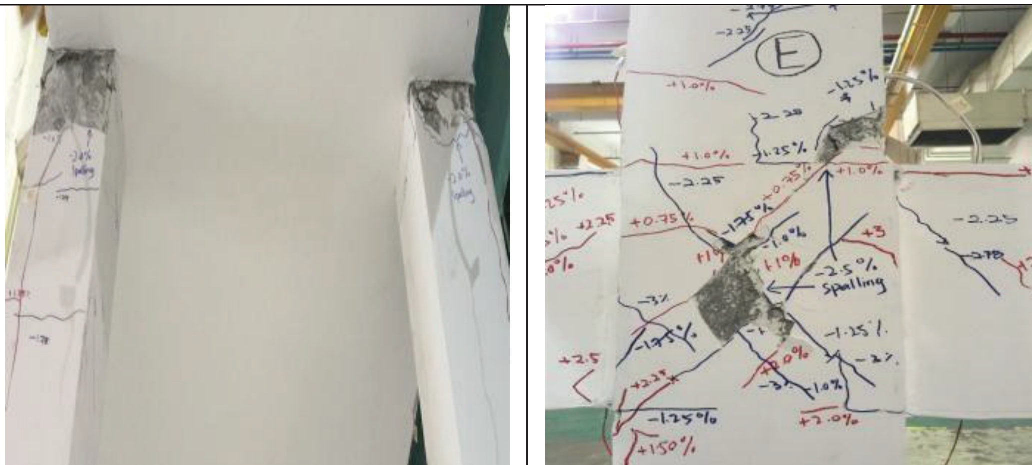


Figure 6. Major crack occurs at beam-column interface at +1.75% drift.

More shear cracks were occurred at exterior beam-column joint as the percentage of drift increases. A typical shear crack occurs due lack of transverse reinforcement in the joint and due to weak column-strong beam design (Uma and Prasad, 2005). At ±2.0% drift, large spalling of concrete was observed at column near corner beam-column joint at second floor level as shown in Figure 7(a). Meanwhile, Figure 7(b) shows the diagonal shear crack and spalling of concrete at middle of exterior beam-column joint and top of column closed to the beam-column joint when applying the -2.5% drift at top of the RC frame under in-plane lateral reversible lateral cyclic loading.



a) Spalling of concrete were observed at bottom corner beam-column joint at ±2.0% drift.

b) Spalling of concrete at exterior beam-column joint subjected to -2.5% drift at second floor

Figure 7. Major cracks occurred at the corner beam-column joint and exterior beam-column joint

Most of the beam-column joints exhibited diagonal shear cracks and become more severe when subjected to bigger drifts. Diagonal cracks occurred because the joint is not provided with additional diagonal reinforcement bar. This kind of failure can be overcome by providing diagonal rebar or fuse bar within the joint. By adding diagonal reinforcement bar along the column gives good effect to the joint (Ghobarah and Said, 2002). The columns will suffer fewer cracks as compare to the column without additional diagonal bar. Diagonal shear failure also occurred due to inadequate reinforcement bars in beam-column joint and column. Figure 9 shows diagonal cracks occurred at the left and right of corner beam-column joints and vertical cracks on the beams of RC moment resisting frame when subjected to in-plane lateral cyclic loading.

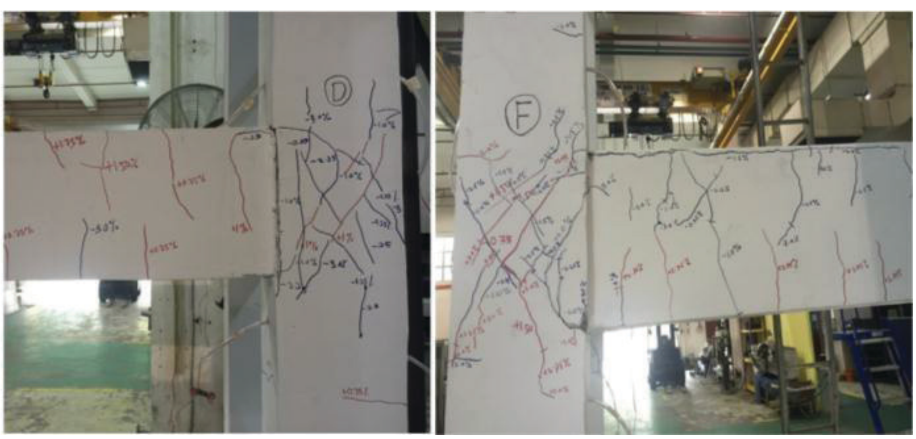


Figure 9. Diagonal cracks at both corner beam-column joints.

From the overall visual observations, the corner beam-column joints exhibited the most severe damage at first floor level as compared to second floor level because second floor level is fix to the steel plate and rigid due to presence of the slab. Meanwhile, the exterior beam-column joints also suffered severe damages, but they can be repaired and retrofitted using CFRP, steel plate, steel angle and enlargement of the column (Hamid et al., 2014b).

Hysteresis Loops

Hysteresis loop demonstrates the energy dissipated under cyclic loading and also measures the amount of work done by RC frame under earthquake loads. Usually, mechanical properties degradation observed during inelastic response range when subjected to repeated lateral cyclic loading (Lu et al., 2011). By plotting the hysteresis loop (load versus displacement), the seismic structural performance of RC moment resisting frame can be determined and interpreted in terms of lateral strength, ductility, stiffness and equivalent viscous damping. Figure 10 shows the hysteresis loop of LVDT1 starting from ±0.2% drift until ±3.0% drift which located at top of the RC frame and parallel to the centre of double actuator. The maximum target lateral drift is 3.0% (85 mm) and maximum lateral load which recorded by load cell is 100kN.

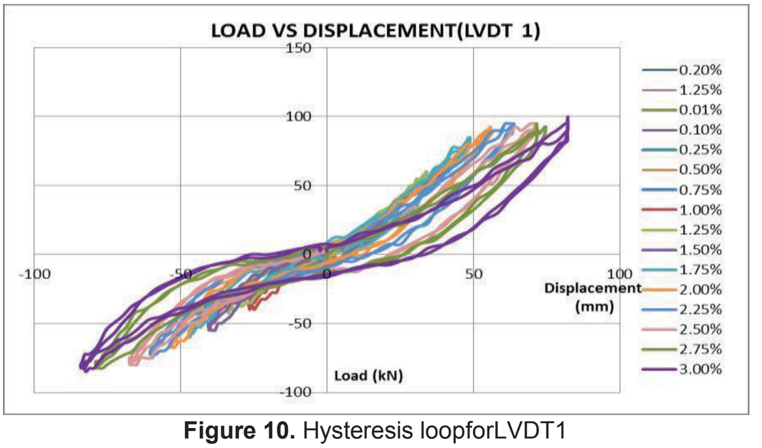


Figure 10. Hysteresis loopforLVDT1

Figure 11 shows the hysteresis loops for LVDT3 starting from ±0.2% drift until ±2.75% drift which located at the centre of corner beam-column joint at first floor of RC moment resisting frame. The hysteresis loops of LVDT3 shows a similar pattern with LVDT1 with same value of the maximum lateral load of 100 kN except for maximum lateral drift of 2.75% drift (43.5mm). There were some discrepancies between the maximum lateral displacement between LVDT1 and LVDT3 due to different values of effective height between them.

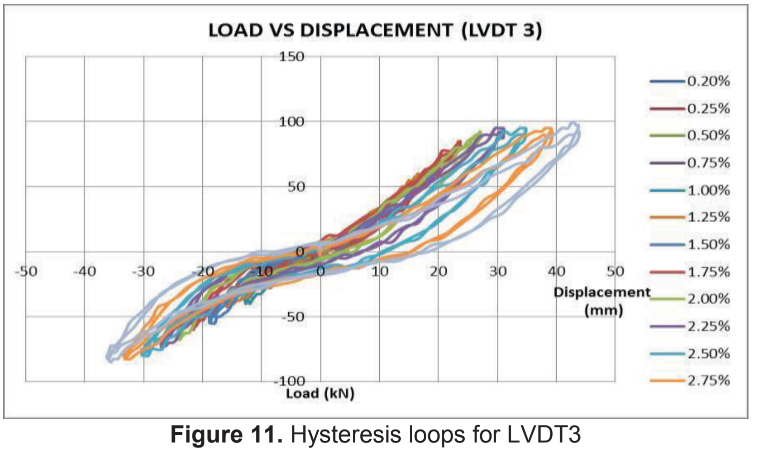


Figure 11. Hysteresis loops for LVDT3

Figure 12 shows the hysteresis loops for LVDT5 starting from ±0.2% drift until ±3.0% drift which placed at the bottom column of the ground beam where the location of plastic hinge zone is expected to occur. The maximum lateral displacement is 4.5 mm and lateral load is 99.98 kN.

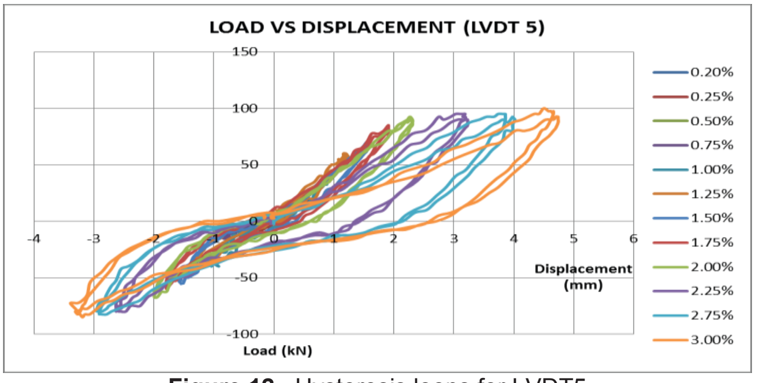


Figure 12. Hysteresis loops for LVDT5

Lateral Strength Capacity

Figure 13 shows the skeleton of load versus displacement under in-plane lateral cyclic loading in pushing and pulling direction starting from ±0.2% drift up to ±3.0% drift. Maximum strength was attained at ±3.0% drift in pushing direction. The specimen behaved in elastic behaviour starting from ±0.2% drift until ±0.75% drift and started to yield before completely fail at ±3.0% drift. The specimen continued to resist higher lateral load and survive until ±3.0% drift before there was no lateral strength left in the structure. The yield lateral displacement (Δ_y) was occurred at ±0.75% drift with the recorded lateral displacement (Δ_y=20.24 mm), yield lateral load (F_y=19.59 kN), the ultimate displacement (Δ_{ult}=82.36 mm) and ultimate lateral load (F_{ult}=99.98 kN). These values were used to calculate the stiffness and ductility in the following subsection.

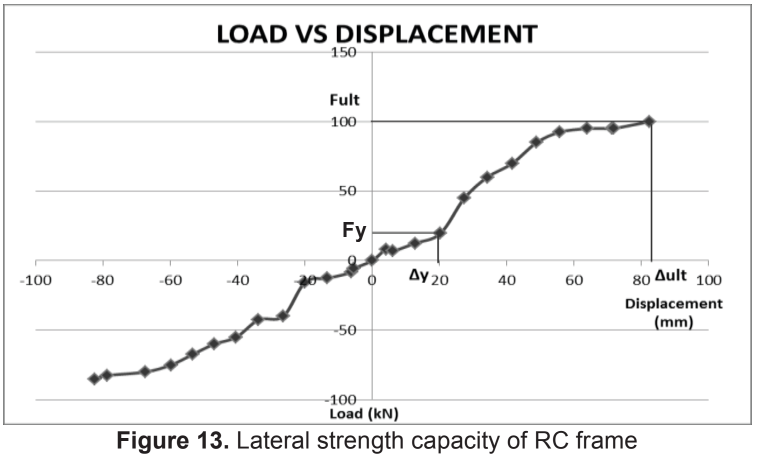


Figure 13. Lateral strength capacity of RC frame

Stiffness and Ductility

Stiffness of structure is needed to resist repeated cyclic loading in the elastic deformation range. There are two types of stiffness when a structure subjected to lateral load; elastic stiffness (K_e) and secant stiffness (K_{sec}) that can be expressed using equations (1) and (2).

$$K_e = F_y / \Delta_y \tag{1}$$

$$K_{sec} = (F_{ult} - F_y) / (\Delta_{ult} - \Delta_y) \tag{2}$$

From the experimental data, the stiffness of specimen for the four initial drifts were decrease in pushing direction however in pulling direction the stiffness only started to decrease at ±0.5% drift. As the target drift increase, the stiffness of the specimen should decrease as discovered by Erberik and Kurtman (2010). Stiffness also can be related to the lateral strength capacity of the structure which is the stiffness will decrease when the structure losses its lateral strength. Table 1 tabulates the calculated values for elastic and secant stiffness together with ductility of RC frame in pulling and pushing directions. The average elastic stiffness in pulling direction is 1.02 kN/mm and in pushing direction is 1.28 kN/mm. The average secant stiffness in pulling direction is 1.19 kN/mm and pushing direction is 1.23 kN/mm.

Ductility is the most important characteristic in structural behavior that subjected to the lateral forces and need to be evaluated from the inelastic cyclic response region perceptive. The displacement ductility (μ) can be calculated by dividing the ultimate lateral displacement by yield lateral displacement. The reinforced concrete structure needs to behave in ductile manner in order to prevent from collapse and brittle failure under reversed cyclic loading in post-elastic range without losing significant strength. In seismic code of practice, the value of ductility should be ranging from $3 \leq \mu \leq 6$ which can be classified as Ductility Class Medium to withstand moderate to strong earthquake and to prolong the displacement. From Table 1, the maximum value of ductility for this specimen is 4.07 in pushing direction and 4.13 in pulling direction at ±3.0% drift. In seismic design, close spaced of stirrup or shear reinforcement spacing can provide good confinement of concrete and large amount of longitudinal bar is required in order to achieve higher ductility for the structure (Hamid et al., 2013).

Table 1. Stiffness and Ductility of the RC frame

Pulling Direction					
Drift (%)	***Load (kN)***	***Disp. (mm)***	***Ke (kN/mm)***	***Ksec (kN/mm)***	***Ductility, (μ)***
0.2	5.6	5.52	1.01	-	0.28
0.25	8.4	6.26	1.34	-	0.31
0.5	12.6	13.24	0.95	-	0.66
0.75	15.4	19.92	0.77	-	1.00
1.0	39.99	26.42		3.78	1.33
1.25	42.49	33.72	-	0.34	1.69
1.5	54.99	40.38	-	1.88	2.03
1.75	59.99	46.96	-	0.76	2.36
2.0	67.49	53.4	-	1.16	2.68
2.25	74.99	59.8	-	1.17	3.00
2.5	79.99	67.34	-	0.66	3.38
2.75	82.49	78.8	-	0.22	3.96
3.0	84.99	82.36	-	0.70	4.13

Pushing Direction					
Drift (%)	***Load (kN)***	***Disp. (mm)***	***Ke (kN/mm)***	***Ksec (kN/mm)***	***Ductility, (μ)***
0.2	8.4	4.14	2.03	-	0.20
0.25	7	6.18	1.13	-	0.31
0.5	12.6	12.8	0.98	-	0.63
0.75	19.59	20.24	0.97	-	1.00
1.0	44.99	27.4	-	3.55	1.35
1.25	59.99	34.18	-	2.21	1.69
1.5	69.99	41.6	-	1.35	2.06
1.75	84.99	48.86	-	2.07	2.41
2.0	92.49	55.76	-	1.09	2.75
2.25	94.98	63.78	-	0.31	3.15
2.5	94.98	71.32	-	0.00	3.52
2.75	94.98	71.66	-	0.00	3.54
3.0	99.98	82.32	-	0.47	4.07

Equivalent Viscous Damping

Equivalent viscous damping is defining as ability of structure to dissipate energy during earthquake and purposely to determine the amount of energy dissipated in a cycle of deformation which area of energy dissipated (E_D) and elastic strain energy (E_{so}) are determined from each of the hysteresis loop. Figure 14 shows equivalent viscous damping was calculated for every drift using acquired dissipated energy and strain energy for first cycle and second cycle. Based on the result, the value of equivalent viscous damping for first cycle is higher compared to the second cycle. The equivalent viscous damping for the first and second cycle for each drift can be calculated using Equation (3) as defined below:

$$\xi = \frac{E_D}{4\pi E_{so}} \qquad (3)$$

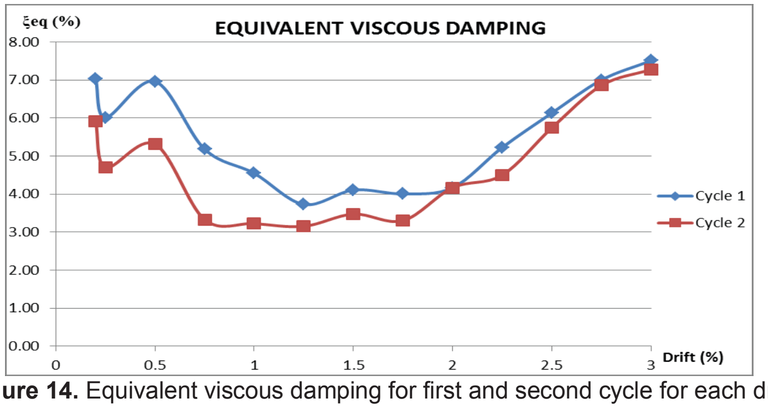


Figure 14. Equivalent viscous damping for first and second cycle for each drift

Stress-strain Relationship

Figure 15 shows stress-strain relationship of strain gauge which labelled as SG13 which located at the column of the second floor RC frame. The maximum value of strain for SG 13 is 3199 μm/m or 0.0032 with corresponding stress is 281.006 kN/mm^2 at lateral load of 94.98 kN of ±2.75% drift.

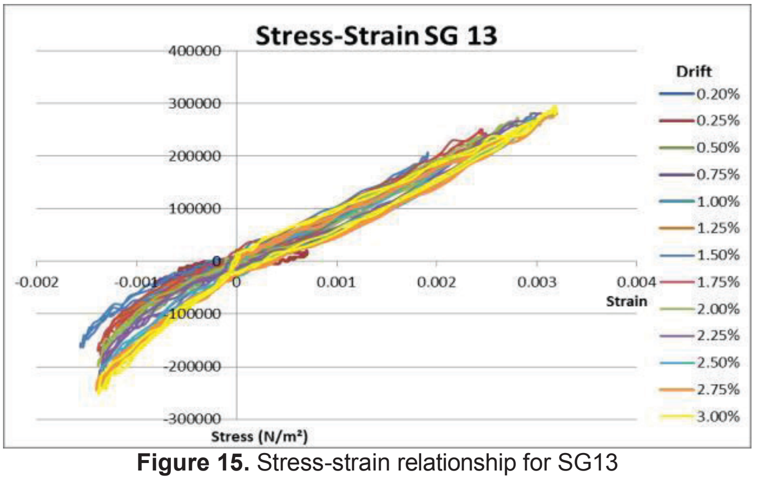


Figure 15. Stress-strain relationship for SG13

CONCLUSIONS

Based on the visual observation, experimental result and data interpretation, the conclusion can be drawn as follows:

1) Based on the visual observation, the initial cracks at RC moment resisting frame started to occur at column under ±0.5% drift and behave elastic manner whereas cracks at beam initiated when subjected to +0.75% drift. Shear crack also observed at beam-column joint at this drift. The shear cracks and diagonal cracks concentrated at beam-column joint of first floor at -2.0% drift and -2.5% drift, respectively.

2) The ultimate lateral strength and lateral displacement recorded at LVDT1 are 99.98kN and 82.32mm, respectively and reached at ±3.0% drift in pushing direction.

3) Stiffness of specimen is decreasing as the lateral load and lateral displacement are increasing. The value of stiffness at ±3.0% drift is 0.47 kN/mm in pushing direction and 0.70 kN/mm in pulling direction.

4) Ductility of RC moment resisting frame is 4.07 in pushing direction which lies within the minimum range of ductility (3≤μ≤6) for a structure to survive under moderate to severe earthquake while the value of ductility in pulling direction is 4.13. The result shows that value of ductility increase with the increasing of target drift with the maximum ductility is at ±3.0%.

5) The highest value of equivalent viscous damping is 7.51% from first cycle and 7.28% from second cycle. The value of equivalent viscous damping of first cycle is higher than second cycle because more energy is required in first cycle to resist lateral force. First cycle is implies for first strike of earthquake which usually is more strong compared to the aftershock represented by the second cycle.

6) The maximum strain from stress versus strain relationship is 3199 µm/m with corresponding lateral load is 94.98 kN from SG13 located near the corner joint A at the top of the RC frame. The steel reinforcement behaves in inelastic behavior because maximum strain is beyond the yield strain limit.

ACKNOWLEDGEMENTS

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PULL-OUT BEHAVIOUR OF TWO DIFFERENT GLUE LINES THICKNESS GLUED-IN STEEL DOWEL FOR KEMPAS SPECIES

Tengku Anita Raja Hussin[1], Sanjay Boss[1] and Rohana Hassan[2]
[1]Faculty of Engineering & Technology Infrastructure', Infrastructure University Kuala Lumpur, Malaysia
[2]Faculty of Civil Engineering, Universiti Teknologi MARA, Malaysia

Abstract
The most important part in timber structural element is the joint. Currently, the major types of connections available are the mechanical joints or adhesive joints. The glued-in dowel has been used for the past 30 years however the available data of this method using tropical timber is still limited. Glued-in steel dowel in the timber connection is one of the assuring techniques and it's provides better stiffness and strength than the conventional connection. This research was conducted to determine the strength of the glued-in steel dowel for Kempas species and the types of failure modes were observed. The pull-out was tested with different thickness that is 2mm and 3mm of glueline with a rate of 1mm/min and the failure modes were observed after the testing of pull-out test. Sikadur® 52 is the adhesive used for the strengthening purposes. The dowel glued-in steel dowel is 10 mm in diameter from S 275 steel type. For the results; the maximum pull-out strength and the maximum shear stresses for glueline 3mm is 47% and 31% higher than 2mm glue line thickness respectively. Therefore, it is proven that the 3mm glueline thickness is the optimum glueline thickness for 10mm glued-in steel dowel.

Keywords: *Pull-out; timber joint; solid timber; kempas*

INTRODUCTION

The timber connection is considered as a very significant area of engineering studies and the common types of connections available are the mechanical joints or adhesive joints. These traditional methods are evaluated by checking on some of the factors such as the shear strength, tensile strength, ductility, costs, aesthetics values, etc. In year 1965, the first ever design of the timber connection with the glued-in metal rod was performed in Sweden and then was followed by a research on the glued-in bolt in a glue laminated timber rotor for the wind turbine. Timber has multiple type of inadequacy when comes to its configuration, which leads it to have most common types of failure in its timber structure.(Gattesco et al., 2010).

The utmost insufficiency of a timber structure is its connection members, types, geometry of the structure and the type of bracing, etc. That is in relation to the dynamic and static loading which exerted to the structure, the slenderness of the timber, the instability of the timber, and not to forget the defect of the lumber and the accidental factors. To determine a ductile failure instead of a failure on the rod's splintering by Gattesco et al. (2010) the concentration was more toward the role of the steel strength and the bar diameter of the steel bar (Rods, 2003). In this study, the scope is narrowed down to the part where it focuses closely on the timber's connections only. According to researcher Harvey and Ansell, "the rod surface preparation and the thickness of the glueline were found to be very important factors in determining the strength of the connection"(Ahmad et al., 2011). Nevertheless, their assumption and finding are not enough for as the main factor that is the timber being a different kind of species. Their assumption and finding are limited to only softwood species and not for tropical species. Very little information are available for the structural performance of tropical timber such us for bending and tensile performance, one of the very recent is the ~~s~~tructural timber beam strengthened with carbon fiber reinforced polymer made of Yellow Meranti ("Bending Behavior of Timber Beams Strengthened," n.d.). The bonding behaviors were tested between the Glass Fiber Reinforced Polymer rod and the glulam timber by test (Jorge & Branco, 2011). The results obtained were the rod that has rougher surface will have more bonding strength, the depth of the groove is important also where the depth has to be at least 3 times the thickness of the rods and the deeper the bonding length, the stronger is the bonding (Jorge & Branco, 2011). A method of calculating the ultimate strength in pullout test was done using the glued-in rod, which is embedded in perpendicularly to the grain direction. The factors that were considered as a factor that influences the ultimate strength of the pull out are the embedment depth and edge distance. The results showed that there is a linear relationship between the embedment depth and the pullout strength (Steer, 2001).

The relationship between the strength of the bonding and the variable were examined. Maximum Pull-out Strength and Shear Stress were calculated by these formulas:

$$\tau_{t\alpha} = \frac{P_{max}}{\pi.\emptyset_{hole}.L} \text{ (Timber} - \text{Adhesive)} \quad (1)$$

$$\tau_{r\alpha} = \frac{P_{max}}{\pi.\emptyset_{hole}.L} \text{ (Rod} - \text{Adhesive)} \quad (2)$$

Where,

$\tau_{t\alpha}$ = Shear Stress at timber − adhesive, MPa

$\tau_{t\alpha}$ = Shear Stress at timber − adhesive, MPa

π = 3.14159

$\emptyset_{rod}$ = Diameter of rod, mm

$\emptyset_{hole}$ = Diameter of hole, mm

L = Length of embedded dowel, mm

The average values of each glueline thickness were calculated and averaged values with its standard deviations were tabulated by using formula 3;

$$sd = \sqrt{\frac{\sum(x-\mu)^2}{N}} \quad (3)$$

where,

$N = number\ of\ specimens$

$\mu = means\ specimenload\ or\ shear\ stress.$

The purposes of the research are to determine the average maximum pull-out strength and stress of the glued-in timber connection by using different thickness of glueline two different thickness of glue line that are 2 mm and 3 mm and the failure modes of the pull-out test were observed.

MATERIAL

The Kempas timber species is used in this study. The dowel tested in this study is S 275 as classified in Eurocode 5 (Steer, 2001).The size of the dowel is 10 mm in diameter and 200 mm length. The edge of the dowel was smoothed and the part that bonded was grassed with sand paper in order to avoid any top glossy layer react with the adhesive. The adhesive used is the Sikadur® 52 which also known as low viscosity crack injections epoxy.

EXPERIMENTAL TEST-UP

The length and the depth of the cuboid are at least 52mm x 60 mm (Broughton & Hutchinson, 2001). Therefore, the sizes of the total numbers of 23 specimens is dimensioned as 100 mm × 100 mm × 60 mm and the hole diameter are 16 mm (Figure 1). The total numbers of dowels are 23 with the length of 200 mm and total numbers of O-ring are 46 nos.

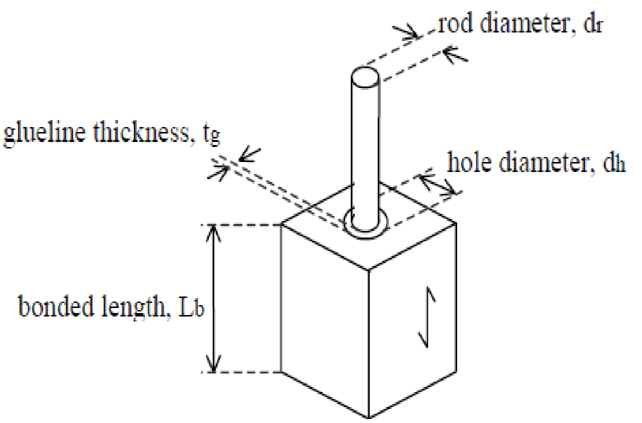

Figure 1. Schematic diagram of the pull-out test specimen

Adhesives used in this study are Sikadur® 52 was supplied by Sika Sdn. Bhd. Malaysia. It is gap filling, thixotropic and structural two-part adhesive, based on a combination of epoxy resins and special filler, designed for use at normal temperature between +8°C and +35°C. There are two parts in the mixing of adhesive, component A, contains epoxy resin and can cause skin sensitization after prolonged. Component B is the hardener and contains amines.

The proportions that needed to be used are 2:1, either by volume or by weight. Both portions had to be mixed together for at least 3 minutes thoroughly so that it could be used. The timber had to be glued with a layer of aluminum plate in order to prevent leakage. Then, the O-ring has to be placed at the bottom of the hole and close it with another O-ring at the top of the timber surface. This O-ring helps the dowel to be positioned precisely in the middle of the hole.

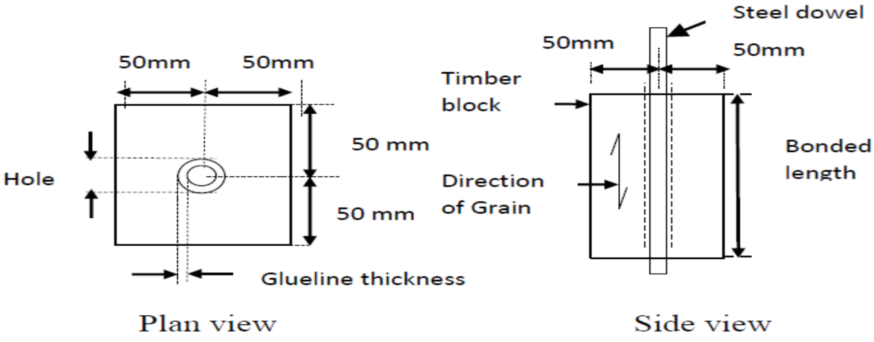

Figure 2. Schematic diagram of the pull-out test specimen

Figure 2 shows the configuration of the specimen and Table 1 reports properties of the materials used for the pull-out tests. The steel dowel 10mm was chosen due to their readily availability in the market. High tensile steel bars were therefore used in this experiment so as to provoke shear failure to occur within the timber close to the joint. The surface of the steel bars was deformed or threaded in order to enhance mechanical interaction between the resin and the bars.

Sikadur® 52 (thickness 2&3 mm) adhesive are strong and durable and do not require high pressure during their application and curing. They are reasonably tolerant with regard to glueline and temperature variations(Broughton & Hutchinson, 2001).One hole of diameters 14 mm and 16 mm (for 10 mm high tensile steel bars with adhesive thickness 2mm and 3mm respectively), with varying bonded lengths were drilled using a vertical drill, fitted with sharp auger bit, parallel to the grain through the entire length of each timber block.

The pull-out test was done with a 1000 kN capacity of Universal Testing Machine (UTM). The steel dowel was attached with a gripping jig that held on the top of the steel dowel. A rig plate was prepared in order to insert the sample, the rig plate consist of top plate, bottom plate with a steel rod attached at the middle, threaded rod, bolts that made out of aluminums. Then, the rig plate was placed on the UTM machine and clamped from the bottom steel rod. The sample was inserted into the rig plate and clamped from the top jaw at the steel dowel.

The sample was placed in a way that the sample cannot move in any direction (Figure 4). Finally, the pull-out of the steel dowel was done with the 1mm/min loading rate.

Figure 3. The pull-out test specimens

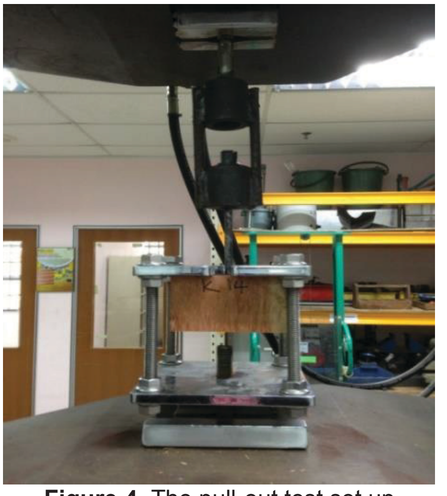

Figure 4. The pull-out test set up

EXPERIMENTAL RESULTS

The effect of the parameter was investigated in this research. The variable was the glueline. The relationship between the strength of the bonding and the variable were examined. Various failures modes are also recorded. Average shear stress at the timber/adhesive interface of the samples for a given bonded length is also illustrated.

Modes of Failure

Figuring out modes of failure is a very important, because in order to make improvement on the structure, the weakest link of the structure has to be identified. It is known that the pull-out test will make the timber, adhesives and the dowel to have shear stress on its surface. Thus, it is the matter of identifying the location of the failure that is crucial.

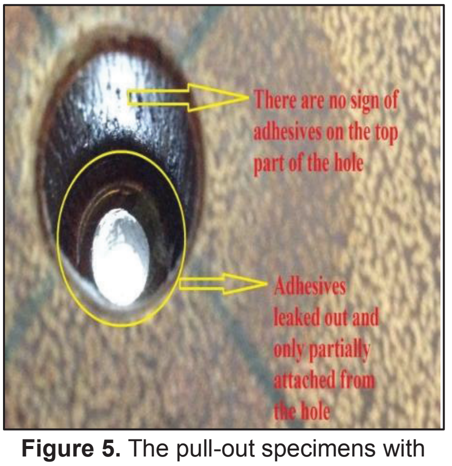

Figure 5. The pull-out specimens with partially filled hole.

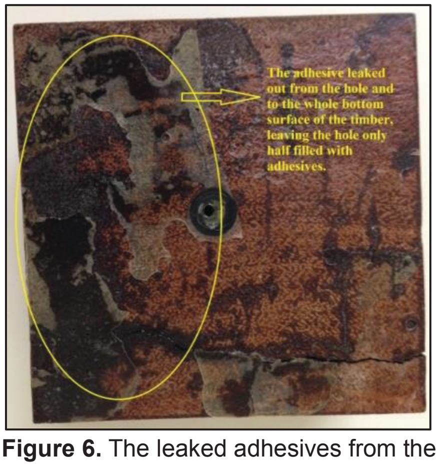

Figure 6. The leaked adhesives from the bottom of the timber cuboid

The Figure 5 presents the pull-out specimens with partially filled hole and the Figure 6 presents the leaked adhesives from the bottom of the timber cuboid.

Figure 7. The sample filled with adhesive

Figure 8. The grazed region of the adhesive

Figure 7 present the sample that can be sed for analysis, as the timber hole is filled completely. This leak was due to the chemical reaction between the bottom of the timber was glued with an aluminum plate using the paper glue and the Sikadur 52 adhesives. During the curing process, the adhesive Sikadur 52 leaked out excessively from some of the samples, thus reducing the strength during the pull-out. Figure 8 shows the grazed region of the adhesives. The maximum pull-out load was determined from the graphs and tabulated.

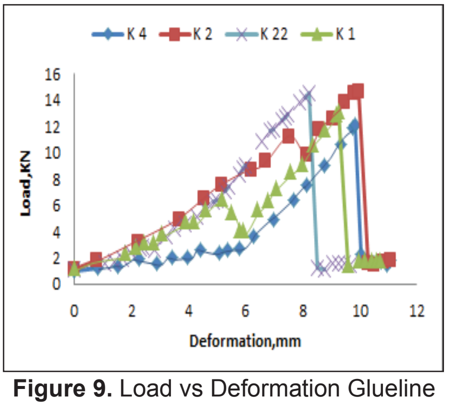

Figure 9. Load vs Deformation Glueline thickness: 2 mm

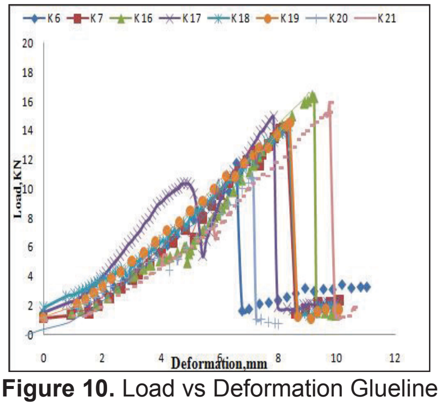

Figure 10. Load vs Deformation Glueline thickness: 3 mm

The maximum pull-out strength was obtained from each graph. The highest point is considered as the maximum pull-out strength of the timber joint. After obtaining the maximum pull-out strength, the maximum shear stress at the adhesive-rod and the maximum shear stress at the adhesive-timber were calculated using equation 3.1 and 3.2.

The sample calculations are presents below for the timber-adhesion and rod-adhesion:

$$\tau_{ta} = \frac{P_{max}}{\pi.\emptyset_{hole}.L} = \frac{14.53 \times 10^3}{\pi \times 12 \times 60}$$
$$\boldsymbol{\tau_{ta} = 6.42\ MPa}$$

$$\tau_{ra} = \frac{P_{max}}{\pi.\emptyset_{rod}.L} = \frac{14.53 \times 10^3}{\pi \times 8 \times 60}$$
$$\boldsymbol{\tau_{ra} = 9.64\ MPa}$$

Table 1. The maximum pull-out strength, maximum shear at the timber-adhesion, τ_{ta} and maximum shear at rod-adhesion, τ_{ra}

Timber Marking	Glueline Thickness, mm	Maximum Load, kN	Maximum Shear at τ_{ta} ,MPa	Maximum Shear at τ_{ra} ,MPa
K 22	2	14.53	6.42	9.64
K 4	2	12.09	5.34	8.02
K 2	2	14.71	6.50	9.75
K 1	2	13.19	5.83	8.75
K 6	3	11.79	4.47	7.82
K 7	3	14.22	5.39	9.43
K 16	3	16.40	6.21	10.88
K 17	3	14.95	5.67	9.91
K 18	3	14.29	5.42	9.48
K 19	3	14.54	5.51	9.64
K 20	3	10.75	4.07	7.13
K 21	3	15.89	6.02	10.54

Referring to the Table 2, Fig. 11 and Fig. 12, the effect of the glueline thickness to the strength and stress increases as the thickness increases. For the glueline thickness of 2 mm, the pull-out strength was 13.63 kN and the shear stress was 9.04 MPa, while for the 3 mm glueline thickness, the pull-out strength was 14.10 kN and the shear stress was 9.35 MPa.

Table 2. The average maximum pull-out strength and the average maximum shear stress.

Glueline Thickness, mm	Pull-out Strength		Shear Stress	
	Pmax (kN)	Std. Dev.	τ (MPa)	Std. Dev.
2	13.63	1.230	9.04	0.814
3	14.10	1.928	9.35	1.279

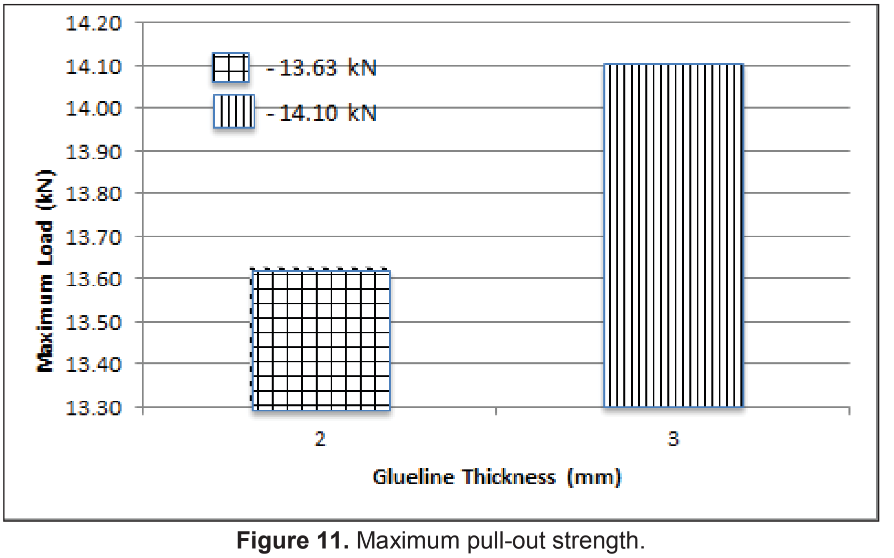

Figure 11. Maximum pull-out strength.

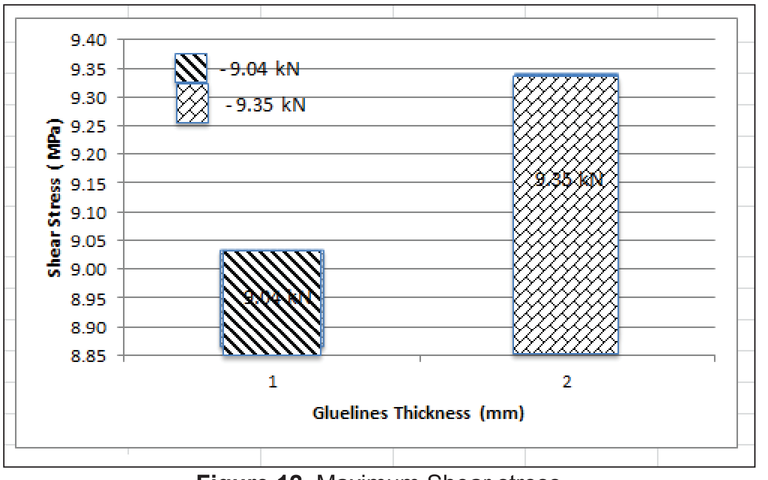

Figure 12. Maximum Shear stress

Anything less or more will have less strength and unable to cater shearing optimally. This indicates that the optimum glueline thickness is 2 mm and 3 mm thickness. Yet in the previous studies (Rods, 2003), proved that the higher the glueline thickness the stronger the glued-in dowel. Therefore, there are some other factors had cause these differences, factors such as the type of dowel and surface of dowel or the type of timber that was used in the testing.

All the timber that undergoes the pull-out test had the same failure that is shear stress due to pulling the dowel away from the block. Yet, for this study purposes, the location of the failures was identified. The failures were mostly dowel-adhesive.

All the timber that undergoes the pull-out test had the same failure that is shear stress due to pulling the dowel away from the block. The failures were mostly dowel-adhesive. This failure happens at the area where the dowel is bonded with the adhesive. The failure at this position is most probably because of the dowel surface area are not being cleaned properly or oily dowel but the dowels were cleaned and checked properly prior to the gluing. Figure 13 and Figure 14 below shows the specimens that failed at dowel-adhesive and timber-adhesive respectively.

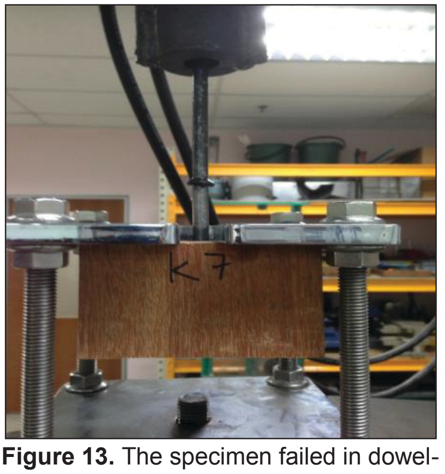

Figure 13. The specimen failed in dowel-adhesive

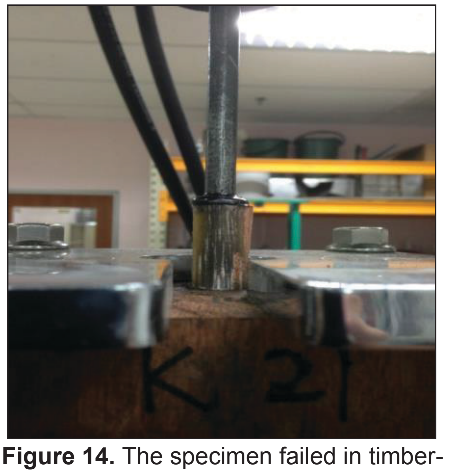

Figure 14. The specimen failed in timber-adhesive

CONCLUSIONS

In conclusion, the obtained results for the 2 mm and 3 mm glueline thickness are the maximum pull-out strengths and the shear stresses with a value of 13.63 kN and 14.10kN and the 9.04MPa and 9.35MPa, respectively. Therefore, the result shows that the 3 mm glueline thickness is the optimum glueline thickness.

Similar failure modes were observed (Ahmad et al., 2011). There were four types reported from previous study (Yusof Ahmad.; 2010). There are two types of failure were observed in this study. The specimens failed in the mode of adhesive-dowel, yet one sample failed in timber-adhesive mode. This might happen because the surface of the timber was burned by drilling machine during the drilling process.

RECOMMENDATIONS

1) In this research, there were many other factors that affect the results. Thus, further researches regarding the glueline thickness should be done in order to obtain a standard value.
2) There is no standard available for research, thus by doing more researches on the glued-in connection; a standard could be made for Malaysia tropical timber.
3) The adhesives strength and bonding-ability has to investigate, in order to obtain the maximum pull-out strength. The other types of adhesives also have to be looked into, for better outcome.
4) Instead of using dowel or circular rod, try using plates for the connection.

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PHYSICAL PROPERTIES OF PUMICE AND ITS BEHAVIOR AS A COARSE AGGREGATE IN CONCRETE

Marco Caiza, Claudio Gonzalez, Theofilos Toulkeridis and Hugo Bonifaz
Departamento de Ciencias de la Tierra y la Construcción, Universidad de las Fuerzas Armadas ESPE, Av. Gral. Rumiñahui, P.O.BOX 171-5-231B, Sangolqui, Ecuador

Abstract
The use of lightweight concrete has gained acceptance and popularity in the construction industry worldwide. There are many methods to create lightweight concrete, one of them is the usage of pumice as a coarse aggregate. The main objective of this study has been to experimentally determine the physical properties of volcanic pumice from north-central Ecuador, when used as a coarse aggregate in concrete. Samples of pumice, conventional coarse aggregate and conventional fine aggregate were taken in order to perform the granulometry, dry density, water absorption, degradation, moisture content and unit mass assays being compliant to ASTN normative. Additionally, the proportioning of the mixture has been calculated according to ACI 211, creating five test cylinders made of hydraulic concrete with conventional aggregate and five test cylinders made of hydraulic concrete using pumice aggregate, testing their compressive strength in different time periods in order to compare the results of both proportioning afterwards.

Keywords: *Pumice, lightweight concrete, proportioning, lightweight coarse aggregate, compressive strength.*

INTRODUCTION

Pumice is a very well-known glassy igneous rock of volcanic origin, having a high porosity and low density, possessing a cream white or occasionally grey color (Hossain, 2004; Bell, 2013). It is a natural lightweight material formed due to the rapid cooling of molten volcanic mass (Ankith, 2014; Tiab and Donaldson, 2015). This material is frequently used as aggregate for lightweight concrete in some countries around the world (Hossain, 2004; Amato et al., 2012; Campione et al., 2015). However, in the Ecuadorian industry its usage has been focused in the manufacturing of masonry blocks or as a fine aggregate for asphalt mixtures (Crespo, 2015), thereby relegating its use as an aggregate for structural concrete due to it being considered a low-quality aggregate (Martinez, 2014). In spite of this there are reasons that justify its structural usage; one of them and perhaps the most important one is taking advantage of the abundance of this material in volcano-surrounding areas, originating from past eruptions (Murdock et al., 1979; Walker, 1981; Mehta and Mehta, 1986), a factor that can directly influence the production cost of concrete (Syverson, 2004; Akram et al., 2009; Manasseh, 2010; Minapu et al., 2014), the implementation of civil works is another reason to employ pumice, given that the weight of the structures is an influencing factor in the design and dimensioning of structural elements, as well as noticeable cost savings in the foundation due to the effect of reducing its own weight (Mang'uriu et al., 2012).

Considering that the Ecuadorian coast is located fifty kilometers away from the convergence zone of the South American and Caribbean continental plates with the oceanic Nazca plate (Pardo-Casas and Molnar, 1987; Pindell and Barrett, 1990; Beck, 1993), being one of the most seismic zones of the planet, liberating around 15% to 20% of the total telluric energy of the whole planet (Giesecke et al., 2004), Ecuador becomes a permanent seismic hazard zone (Parra et al., 2016; Toulkeridis et al., 2017). Therefore, it is imperative to look for different forms of lowering the structural dead load, a fact being offered by the characteristics of Pumice, presenting less density than conventional aggregates (Parhizkar et al., 2012; Ramasamy and Muralitharan, 2015).

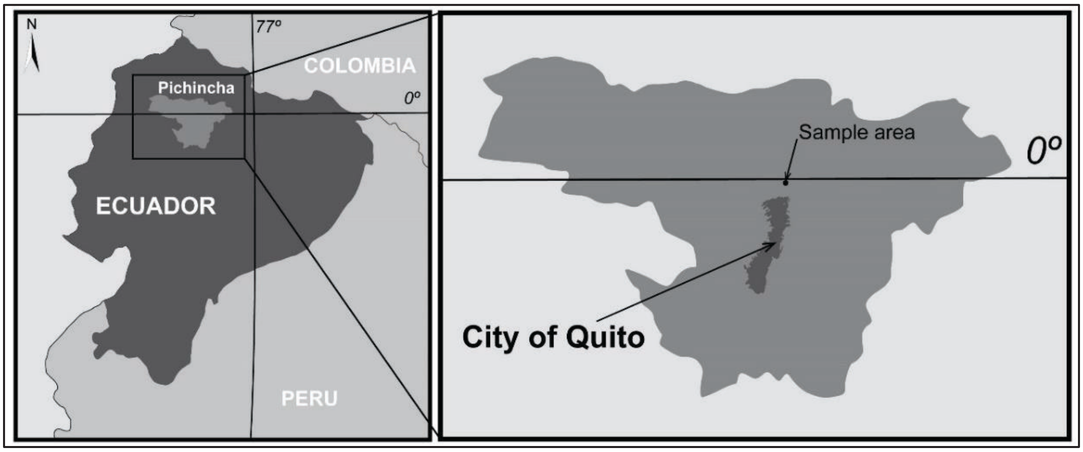

Figure 1. Geographical location of the procurement zone of the pumice and other study aggregates. Adapted from Toulkeridis et al. (2016).

The reduction of dead load in the structure becomes equivalent towards an increase in the capacity of bearing live load (Alexanderson, 1979) resulting into a method of resource optimization. The objective of this investigation has been to determine the effects of pumice as a coarse aggregate in the manufacturing of concrete and to perform an objective comparison of results against concrete manufactured with conventional coarse aggregate. However, in order to consider pumice as a construction material its properties need to be evaluated beforehand (Gündüz and Ugur, 2004). Therefore, it's necessary to thoroughly analyze the materials that will be experimentally utilized in construction. This constitutes the backbone of any material analysis that uses models of applied engineering (Gündüz and Ugur, 2004). Volcanic pumice applied as a replacement coarse aggregate for the study of compressive strength through the manufacturing of concrete cylinders for this investigation was acquired from the Mitad del Mundo sector in the Pichincha province, Ecuador (Figure 1).

MATERIALS AND METHODS

Various trials were performed in the lab on the pumice lightweight aggregate and on the conventional fine and coarse aggregates in order to determine their mechanical and physical properties, with the goal of researching their suitability as concrete aggregates. Identical assays were performed on the conventional aggregate, being granulometry, dry density, water absorption, degradation, moisture content and unit mass.

Granulometry: The size of the aggregates has a direct effect on the concrete's mechanical behavior. For this reason, the classification of the pumice lightweight aggregate and the conventional aggregate were performed in order to determine if they're qualified as concrete aggregates according to ASTM C136 and Norm AASHTO No. T 27 (ASTM, 2007;

Bailey and Baldini, 2007; Ameri and Behnood, 2012; Maier and Durham, 2012), the results of the uniformity coefficient Cu and the curvature coefficient Cc, which defines if the soil is well or badly graded, are also discussed (Table 1; Figure 2).

Table 1. Granulometry of the lightweight (pumice) and conventional aggregates obtained in the laboratory

GRANULOMETRY OF THE LIGHTWEIGHT AGGREGATES (PUMICE)				
Sieve number	Mass retained (g)	Mass accumulated	% Accumulated	% Accumulated passing
No. 1"	605.20	605	8.6	91.35
No. 3/4"	1167.60	1773	25.3	74.68
No. 1/2"	2095.80	3869	55.3	44.74
No. 3/8"	1073.60	4942	70.6	29.40
No. 4	1773.50	6716	95.9	4.06
No. 8	162.10	6878	98.3	1.75
No. 8 passing	122.40	7000		
SAMPLE INITIAL MASS: (g)		7012.2		
NOMINAL MAXIMUM SIZE		1"		
GRANULOMETRY OF THE CONVENTIONAL AGGREGATES				
Sieve number	Mass retained (g)	Mass accumulated	% Accumulated	% Accumulated passing
No. 1"	1993.80	1994	16.7	83.29
No. 3/4"	4079.70	6074	50.9	49.10
No. 1/2"	3781.80	9855	82.6	17.41
No. 3/8"	1222.30	11078	92.8	7.16
No. 4	783.10	11861	99.4	0.60
No. 8	9.60	11870	99.5	0.52
No. 8 passing	62.10	11932		
SAMPLE INITIAL MASS: (g)		11948.43		
NOMINAL MAXIMUM SIZE		1"		

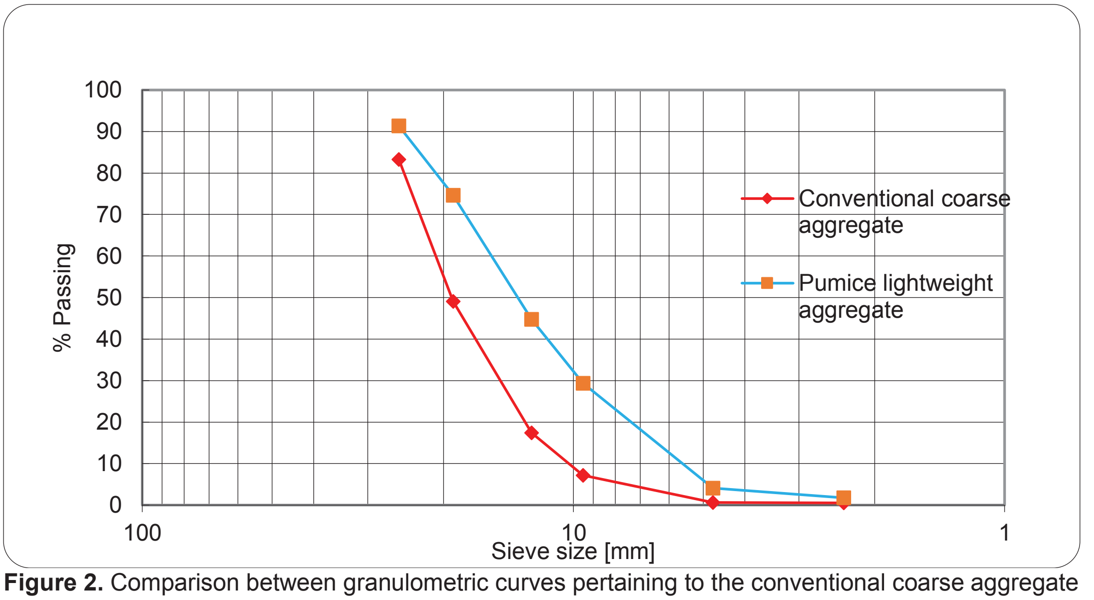

Figure 2. Comparison between granulometric curves pertaining to the conventional coarse aggregate and the pumice lightweight aggregate

Density and Water Absorption: These two physical properties were determined according to ASTM C127-07 for the conventional coarse aggregate, whereas the density of pumice has been determined according to previously established studies (Jimenes-Salas and De Justo, 2001); (Ameratunga et al., 2016), given that method ASTM C127-07 cannot be applied to a lightweight porous material such as pumice (Table 2).

Table 2. Density and Absorption of the lightweight and conventional aggregates

DENSITY AND ABSORPTION OF THE CONVENTIONAL COARSE AGGREGATES (ASTM C 127-07)			
Property		**Symbol**	**Value**
Mass of the oven dried sample	[gr]	A	3837.6
Mass of the saturated sample, superficially dry	[gr]	B	3998.3
Apparent mass in water of the saturated sample	[gr]	C	2288.62
Specific weight of water	[g/cm^3]	γ	1.00
Apparent dry density	[g/cm^3]	A/(A-C)	2.478
Specific Weight	[g/cm^3]	A/(B-C) * Y	2.24
Absorption %	[%]	(B-A)/A * 100	4.1
ABSORPTION OF THE LIGHTWEIGHT AGGREGATE (ASTM C 127-07)			
Property		**Symbol**	**Value**
Mass of the oven dried sample	[gr]	A	454.96
Mass of the saturated sample, superficially dry	[gr]	B	500.00
Absorption %	[%]	(B-A)/A * 100	9.90
DENSITY OF THE LIGHTWEIGHT AGGREGATE (Jiménez –Salas, 2001)			
Property		**Symbol**	**Value**
Petri box weight + mercury	[gr]	A	761.20
Petri box weight + spilled mercury	[gr]	B	678.75
Mercury density	[g/cm^3]	C	13.50
Mas of mercury	[gr]	D	82.45
Mass of Pumice	[gr]	E	4.40
Volume of pumice	[cm^3]	F= D/C	6.11
Pumice density	[g/cm^3]	G= E/F	0.72

Degradation: This trial determines the degradation value of the coarse aggregate, based on the loss of mass due to abrasion and impact using the Los Angeles Machine. The results of this test determine, if the aggregate is suitable to be used as an aggregate for concrete conforming to ASTM C131-03, which itself establishes that if the aggregate's degradation is above 50% it is not capable of resisting abrasion, which renders the material unsuitable for concrete (Table 3).

Table 3. Results of the degradation trials of the conventional coarse aggregate and the lightweight aggregate

Conventional aggregate degradation results			
Property		**Symbol**	**Value**
Dry sample mass before test	[g]	P1	4994.35
Dry sample mass after test	[g]	P2	3202.8
Abrasion percentage	[%]	%=100 (P1 - P2) / P1	35.87
Pumice lightweight aggregate degradation results			
Property		**Symbol**	**Value**
Dry sample mass before test	[g]	P1	4994.35
Dry sample mass after test	[g]	P2	2598.06
Abrasion percentage	[%]	%=100 (P1 - P2) / P1	47.98

Dry and Compact Unit Mass: This trial determines the unit mass or volumetric weight of the coarse aggregate in compact state conforming to ASTM C29-09, values which are necessary in various methods for the design of the proportioning's (Table 4).

Table 4. Dry and Compact Unit Mass of the conventional and lightweight aggregates

Conventional coarse aggregate			
Container No.		**1**	**2**
Mass of empty container	[gr]	7700	7700
Mass of container + Aggregate	[gr]	20020	19996
Mass of aggregate	[gr]	12320	12296
Volume of container	[cm^3]	13646.29	13646.29
Dry and compact unit mass	[g/cm^3]	0.903	0.901
Average unit mass	[g/cm^3]	0.902	
Pumice coarse lightweight aggregates			
Container No.		**1**	**2**
Mass of empty container	[gr]	2101.5	2101.5
Mass of container + Aggregate	[gr]	13221.1	13275.6
Mass of aggregate	[gr]	11119.6	11174.1
Volume of container	[cm^3]	6794.05	6794.05
Dry and compact unit mass	[g/cm^3]	1.637	1.645
Average unit mass	[g/cm^3]	1.641	

Moisture Content: This test determines the percentage of evaporable moisture by drying in a sample of coarse aggregate, both corresponding to superficial moisture and moisture contained in the aggregate's pores conforming to ASTM C566-04. Materials originating from areas surrounding volcanoes commonly present a higher percentage of natural moisture (Segura Castruit et al., 2003; Table 5).

Table 5. Natural moisture of the conventional and lightweight aggregates

Conventional coarse aggregate			
Container		**1**	**2**
Mass of empty container	[gr]	105.74	131.10
Mass of container + moisture sample	[gr]	1338.86	1277.60
Mass of container + dry sample	[gr]	1324.51	1258.16
Weight of water	[gr]	14.35	19.44
Dry weight	[gr]	1218.77	1127.06
Moisture percentage	[%]	1.18	1.72
Average Moisture [%]		1.45	
Pumice coarse lightweight aggregates			
Container		**1**	**2**
Mass of empty container	[gr]	25.75	25.75
Mass of container + moisture sample	[gr]	141.74	145.87
Mass of container + dry sample	[gr]	135.57	138.97
Weight of water	[gr]	6.17	6.91
Dry weight	[gr]	109.82	113.22
Moisture percentage	[%]	5.62	6.10
Average Moisture [%]		5.86	

Design of the Concrete Mixture: For this study two different proportioning were created conforming to method ACI-211, of which the first one was using conventional coarse aggregate and the second one was replacing the conventional aggregate with lightweight pumice aggregate. The mixture has been designed for a volume of 26507.189

cm^3, which equals five test cylinders. Additionally, the mixture has been designed to reach a compressive strength of 250 Kg/cm^2.

The material used as a fine aggregate for this study, originated from commercial quarries and may be labeled as conventional fine aggregate. The tests to determine the physical properties have been: Apparent Dry Density according to ASTM C28-07a, Percentage of Absorption according to ASTM C28-07a, Natural Moisture according to ASTM C566-04 and Fineness Modulus according to ASTM C136-06. Table 6 demonstrates the proportioning used for the present study.

Table 6: Proportioning for the conventional and lightweight concrete mixtures

Proportioning for 5 conventional concrete cylinders			
Material	**Proportions (volume respect to cement)**	**Dry Weight (kg)**	**Moisture Weight (kg)**
Cement	1	18.256	18.256
Fine aggregate	1.36	24.828	25.623
Coarse aggregate	2.2	40.163	40.756
Water	0.39	7.12	5.964
Proportioning for 5 pumice lightweight concrete cylinders			
Material	**Proportions (volume respect to cement)**	**Dry Weight (kg)**	**Moisture Weight (kg)**
Cement	1	14.32	14.32
Fine aggregate	2.74	39.24	40.49
Coarse lightweight aggregate (pumice)	2.18	31.22	33.05
Water	0.52	7.53	6.06

Molting and Trial of Test Cylinders: The pumice aggregate replaced the conventional aggregate by 100%. This has been performed in order to encounter a quantitative relationship between the mechanical behaviors of the test cylinders of conventional concrete and the test cylinders of lightweight concrete measured under the compressive strength assay according to ASTM C39-05. The resistance of the concrete test cylinders has been tested at 7 days, 14 days, 21 days and 28 days of curing. Additionally, a sample from each mixture, which underwent a rapid curing process, has been applied after 5 days according to ASTM C918-13. The results of the compressive strength behavior were determined and analyzed for each mixture.

RESULTS AND DISCUSSION

Aggregate Properties: When aggregates are too coarse, than they may produce rigid mixtures, whereas aggregates that do not possess a great deficiency or excess in size, having a smooth granulometric curve, will produce more satisfactory results (Kosmatka and Wilson, 2016). For the present study the granulometric curve illustrated in Figure 2 demonstrates the tendency of the lightweight aggregate similar to that of the conventional aggregate. There, both curves present a smooth development. This indicates that the aggregates' nominal sizes do not suffer any abrupt variations and maintain some similarity among each other. That is reflected in the values of the uniformity coefficients, being 2.02 for the conventional aggregate and being 2.78 for the pumice aggregate. In spite of being low values and indicating that the cuve doesn't extend that much horizontally, it doesn't present abrupt changes in internal diameters, something reflected by the values of the curvature coefficients: 1.06 and 1.02 for the conventional and pumice aggregates respectively. On the other hand in the apparent dry density trial the results are quite far apart. Table 2 indicates that the conventional coarse aggregate, with a density value of 2.478 g/cm^3, represents more than 3 times the density of the lightweight aggregate, that has a value of 0.72 g/cm^3. Similar results were presented in the study performed by Mang'uriu et al., (2012), where the density values obtained are 0.574 g/cm^3 for pumice and 1.956 g/cm^3 for the conventional aggregate, both originating from Mai Mahiu, Kenya.

With regards to the water absorption tests, the conventional aggregate has a 4.1% of absorption whereas pumice has more than double the absorption with 9.90% (Table 2). This in turn means that the concrete manufactured using pumice is more porous than the one manufactured using conventional coarse aggregate. Porosity is an important factor that influences the material, given that it allows the entrance of aggressive agents into the concrete matrix, affecting its compressive strength (Quintero Ortiz et al., 2011).

The degradation trial evidenced that the pumice lightweight aggregate demonstrated more loss of mass due to abrasion than the conventional coarse aggregate with abrasion percentages of 47.98% and 35.87% respectively. This has been due to the superficial texture and physical composition of pumice. By contrast, the result of the unit mass or volumetric weight trial reflected that the lightweight aggregate, with a value of 0.902 g/cm^3, has less mass per unit volume than the conventional aggregate, which possesses a value of 1.641 g/cm^3. This is justified by the amount of empty space that pumice presents in its composition.

The moisture content test determined that the pumice lightweight aggregate has a 5.86% humidity in its composition, compared to a 1.45% humidity present in the conventional aggregate. These results indicate that at the moment of setting the pumice lightweight concrete will suffer a greater loss of mass than conventional concrete. This provokes traction forces that give rise to fissures, which results in a decrease in the concrete's compressive strength (Kristiawan, 2006). Therefore, we certainly are able to infer that the results of the compressive strength trial performed on the conventional and lightweight concrete cylinders are influenced by the physical discrepancies of the coarse aggregates used respectively.

Compressive Strength Assay: The compressive strength of the pumice lightweight concrete at 28 days is 174.47 Kg/cm^2, which represents 68.56% of the compressive strength of the concrete manufactured with conventional aggregate, with a value of 254.48 Kg/cm^2 (Table 7; Fig. 3). Similar results were determined in the study performed by Ramasamy and Muralitharan (2015) in which they determined that the compressive strength of concrete manufactured with pumice originating from Tamilnadu in India, represents 56% of the compressive strength of concrete manufactured with conventional aggregate. Furthermore, the results of compressive strength trials performed at 5 days of rapid curing, values that represent roughly 70% of the compressive strength expected at the end of the 28 days. This process is useful in order to perform an early estimate of the results (Table 7; Figure 3).

Table 7. Results of the compressive strength assays for conventional and lightweight concrete

Concrete with conventional aggregate			
Cylinder age (days)	**Cylinder weight (g)**	**Load (kg)**	**compressive strength (kg/cm2)**
5 (rapid curing)	12423.1	28765	181.79
7	12064.8	17885	107.891
14	12136.2	26770	151.492
21	12245.4	36171	200.824
28	12364.8	45572	254.483
Concrete with lightweight aggregate			
Cylinder age (days)	**Cylinder weight (g)**	**Load (kg)**	**compressive strength (kg/cm2)**
5 (Rapid curing)	12423.1	18960	104.486
7	12064.8	15832	89.59
14	12136.2	19832	109.292
21	12245.4	22832	125.824
28	12364.8	30832	174.473

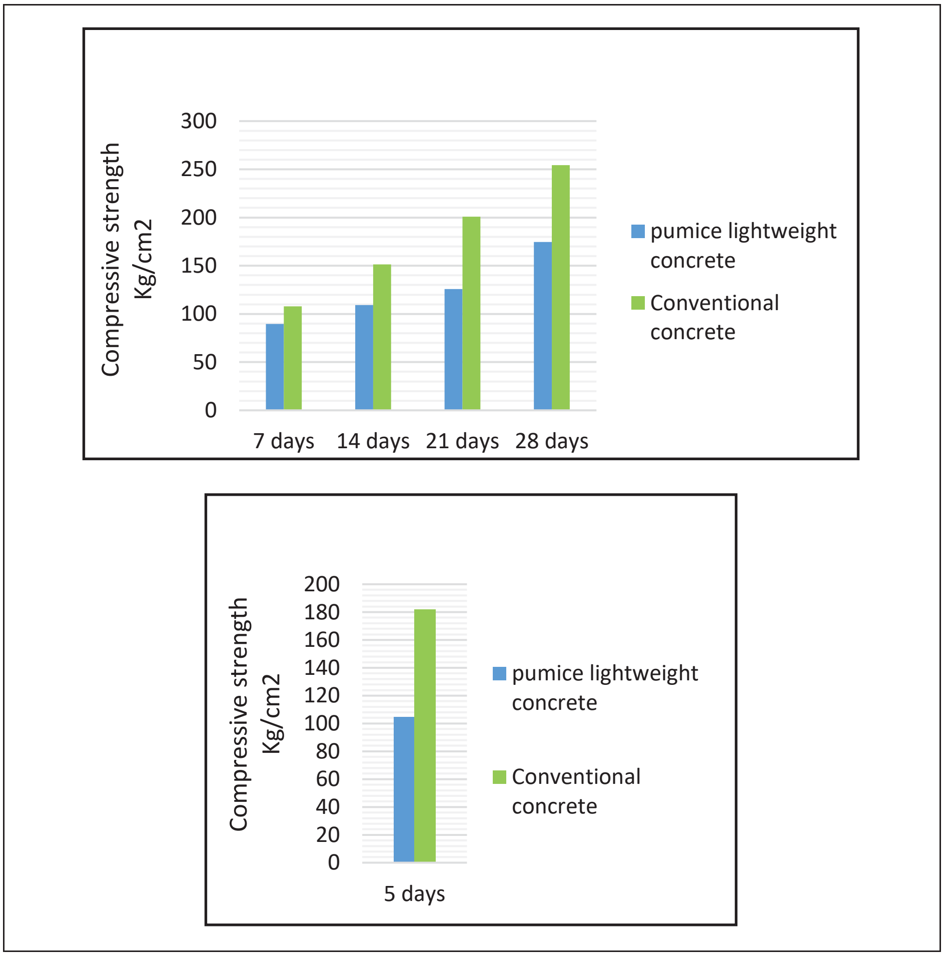

Figure 3. Comparison of the results of the compressive strength trial. Left, trial of 7, 14, 21 and 28 days of curing. Right, trial of five days of rapid curing

Figure 4. Test cylinders of conventional (left) and pumice lightweight concrete (right) after the compressive strength trial.

CONCLUSIONS

Based on the results obtained it is possible to note that when replacing 100% of the conventional aggregate with pumice lightweight aggregate, the result is a lower-quality concrete due to a 31.44% reduction in its capacity to withstand compression. The results demonstrate that the pumice may be used as a coarse aggregate for lightweight concrete thanks to the low density of pumice compared to the density of the conventional aggregate. This occurs as long as the structural load on the construction is light, such as rural single-family dwellings, as well as an aggregate in concrete to be used in subflooring where the service loads are minimal. Obviously, a further benefit and advantage results in the high abundance of the material, especially in volcano-surrounding areas.

The results of the absorption trials demonstrated that pumice, being a porous material, demonstrates a higher absorption than conventional aggregate, a fundamental factor that influences the mixture making process, due to the fact that the high amount of water temporarily absorbed has a direct influence on the range of the design strengths.

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STRENGTH AND CHLORIDE PERMEABILITY OF SELF CONSOLIDATING CONCRETE USING WASTE MATERIALS

Ahmad Ruslan Mohd Ridzuan, Mohd Afiq Mohd Fauzi, Mohd Fadzil Arshad and Nurliza Jasmi
Institute for Infrastructure Engineering and Sustainable Management (IIESM), Universiti Teknologi MARA 40450 Shah Alam, Selangor, Malaysia

Abstract
The utilization of industrial waste materials in construction industries has become an important factor in sustainable development. The selection of correct industrial waste materials specific to design requirement and usage will ensure the success rate of the materials to be used in construction industries. To identify the suitability of the waste materials as construction materials, a study on the properties, performance and durability of the materials in design medium are essential. This research will focus on the strength characteristic and the chloride permeability level of Self Consolidating Concrete (SCC) containing Recycled Concrete Aggregate (RCA) and Waste Paper Sludge Ash (WPSA). The influence of RCA content in the range from 0% to 100% of natural aggregate to the strength characteristic and the chloride permeability level of SCC containing optimum levels of WPSA mixes was identified and comparedwith SCC containing normal mixes. The SCC test specimens cured under water at tested for the compressive strength at age 3-day, 7-day, 14-day, 21-day, 28-day, 56-day and 90-day and chloride permeability were determined at age 28-day, 56-day and 90-day. The result indicated that the compressive strength and chloride permeability of SCC containing 100% RCA replacement show comparable performance with normal mixes of SCC.

Keywords: *Self Consolidating Concrete; Recycled Concrete Aggregate; Waste Paper Sludge Ash; Compressive Strength; Rapid Chloride Permeability Test*

INTRODUCTION

Concrete has been used all over the world and the importance of the concrete cannot be underestimated in our modern society. Concrete, is the composite material by combining cement, fine aggregate (sand), coarse aggregate (rock) and water. It is important to provide good quality of concrete to ensure the safety and durability of concrete structures. The advancement on concrete technology has developed in such manner to improve the concrete quality. One of the most significant technology advances in concrete technology is Self Consolidating Concrete (SCC) (Kartika and Ravi, 2016).

SCC can be defined as the concrete that easily flow able and can be placed under its own weight with little or no vibration at all. The development of SCC is pretty much wider and have been using for almost 30 years. It shows a good sign that these technologies of concrete have been acceptable and provide more safe and durable structures in construction area.

In production SCC, the use of such an admixturehas been always necessary. This is because, the workability of the SCC would increase and segregation can be avoided while placing it, which the flow ability is, depends on it. Therefore, to produce high workability the use of fine particles such as fly ash and silicafume is usually being used (Srishaila et al., 2014; Mohamad et al., 2016).

WPSA is the waste material that came from paper sludge, which can act as part of cement replacement in the SCC mixes. The finest of this material can create more durable of concrete and can be one of the alternatives for the engineer to select the most suitable concrete replacement material for different environments.

Besides that, the aggregate in the SCC mixes can be replaced with other waste materials such as Recycle Concrete Aggregate (RCA) to produce more sustainable of concrete structures. RCA is derived from the demolition of concrete buildings, roads and other infrastructures. The concerning of recycling the concrete aggregate is constantly increasing which contribute the preservation of the natural resources and cost saving considerations of construction projects.

This paper highlighted the strength and chloride permeability of SCC containing of WPSA and RCA is enhancing the understanding of the suitability of these two waste materials into SCC mix. The expected increasing interest and demand in SCC will benefit both the construction industry and the environment if the use of RCA as alternative replacement aggregates and WPSA as alternative replacement cement in SCC is explored and used extensively for new constructions.

MATERIALS AND METHOD

Materials Selection

Ordinary Portland Cement (OPC) Type General Purpose was used as a binder. OPC used is in compliance with BS EN 197-1: 2000 because it has a medium rate of hardening and is suitable for most types of work.

River sand was used as fine aggregate. Fine aggregate in properly graded is essential to successful execution of the work. Fine aggregate was used is of maximum size 5 mm.

Coarse aggregates of maximum size 20 mm crushed aggregates were used in this study. The size of the aggregate selected was according to BS EN 933-1:2012. The coarse aggregate content in SCC is kept either equal to or less than that of the fine aggregate content (The European Guidelines, 2005).

Recycled concrete was obtained from the batching plant at Global Prefab System Sdn. Bhd., Cyberjaya, Selangor. Recycled concrete was deriving from crushed grade 40 concrete. Recycled concrete was crushed using jaw crusher to object Recycled Concrete Aggregate (RCA), and then, the RCA was graded to the size required by using the grading machine. The coarse RCA was compliance to BS 8500-1: 2006+A1: 2012 and BS 8500-2: 2006+A1: 2012. Maximum size of RCA is 20 mm.

Waste Paper Sludge Ash (WPSA) was used as a binder to replacecement. The WPSA was obtained from the paper mill industry at Malaysian Newsprint Industry Sdn. Bhd. (MNI), Mentakab, Pahang.

The type of Superplasticiser (Sp) used in this experiment is GLENIUM ACE 388, also known as Poly Carboxylic Ether (PCE). For all batched, 1.0% (of 100 kg of cement weight) of Sp was added to the concrete mixture. This percentage is based on the cement weight that has been used for allbatches.

Tap water was also used tomix the concrete and curing the concrete specimens. The quality of water is according to the Public Work Department of Malaysia, adapted from BS EN 1008:2009, for concrete work specifications.

Experimental Method

This research was carried out to identify the properties of SCC containing different percentages of coarse RCA replacement level of 0%, 30%, 50%, 70% and 100% for design strength of 30, 35 and 40 N/mm^2. The SCC properties covered in this study include properties in the fresh and hardened state. For this research, the dimension size of the specimen was 100 mm x 100 mm x 100 mm for compressive strength and 50mm (diameter) x 100mm for rapid chloride permeability test. The effect of incorporating RCA on compressive strength of SCC was determined at the age 3, 7, 14, 21, 28, 56 and 90 and chloride permeability was determined at age 28, 56 and 90.

Design of Mix Proportion

The basic components for mix composition of SCC are the same as used in conventional concrete. The SCC mix for this study was designed based on the British method Department of Environment rev 1988 to determine the indicated quantity by weight of the cement content, free water and total aggregates (Fine aggregate and Coarse Aggregate). The mix proportions for grade 30, 35 and 40 N/mm^2 is as shown in Table 1.

Table 1. Mix proportions used in this research

Design Strength	Coarse RCA Replacement Percentage (%)	Cement (kg)	WPSA (kg)	Water (kg)	Fine Aggregate (kg)	Natural Aggregate (kg)		RCA (kg)		Sp (Liter)
						10mm	20mm	10mm	20mm	
	0					300	590	0	0	
	30					210	413	90	177	
30N/mm^2	50	351	39	205	890	150	295	150	295	3.9
	70					90	177	210	413	
	100					0	0	300	590	
	0					290	580	0	0	
	30					203	174	87	174	
35N/mm^2	50	378	42	205	875	145	290	145	290	4.2
	70					87	174	203	174	
	100					0	0	290	580	
	0					285	570	0	0	
	30					199	399	86	171	
40N/mm^2	50	409.5	45.5	205	855	143	285	142	285	4.55
	70					86	171	199	399	
	100					0	0	285	570	

Casting and Curing

The process of casting is where the concrete mix is poured into steel mould. In this study, the fresh concrete was placed inside the cast iron moulds immediately after mixing completed. The specimens were produced in the form of cube and cylinder. The dimension of the cube is 100mm x 100mm x 100mm and the cylinder is 100mm (dia) x 50mm.

After 24 hours casting, the specimens were demoulded and were cured in water until the testing date. The method of curing was according to BS EN 12390-2:2000.

Test Procedures

In this experiment, the following method was used: Slump-flow test for flowability and viscosity. The slump flow test was used to assess the horizontal free flow of SCC in the absence of obstructions. The test method was based on the conventional slump test referred to BS EN 206: Part 9: 2010. The higher the slump flow value, the greater is the ability to fill formwork under its own weight. The acceptable range for SCC is from 550 to 850 mm BS EN 206: Part 9: 2010.

The hardened concrete was tested for the compressive strength which were tested at the age of 3, 7, 14, 21, 28, 56 and 90 and chloride permeability were determined at age 28, 56 and 90. The concrete specimens for this test were 100 mm x 100 mm x 100 mm and the cylinder is 100 mm (dia) x 50 mm. The compressive strength was tested as accordance toBS EN 12390: Part 3: 2009. The rapid chloride permeability was tested as accordance to ASTM C1202-12.

RESULT AND DISCUSSION

Fresh Concrete

Fresh concrete produced in this study were tested for flowability and passing ability to satisfy the requirement for SCC. The results of the slump flow test which determined flowability and the L-box test which determined the passing ability of the concrete are as shown in Table 2.

Table 2. Slump Flow and L-Box Test Result

Design Strength	RCA Replacement Percentage (%)	Slump Flow (mm)	Passing Ability
30 N/mm2	0	693	0.89
	30	660	0.83
	50	655	0.86
	70	640	0.91
	100	620	0.82
35 N/mm2	0	680	0.92
	30	665	0.87
	50	640	0.83
	70	620	0.82
	100	615	0.82
40 N/mm2	0	690	0.92
	30	675	0.88
	50	650	0.90
	70	620	0.86
	100	580	0.84

In this study, the slump flow diameter of all specimens tested lies between 550 mm and 700 mm. This satisfies the requirement for self consolidating concrete as per The European Guidelines, 2005. The results indicated that increasing the percentage of RCA replacement content in the fresh concrete does not cause a detrimental effect on the flowability of the fresh

SCC even though more free water will be absorbed by the increasing RCA content which has a higher water absorption rate.

The Passing Ability (PA) of the fresh concrete was between 0.80 and 0.92. The acceptance criterion for SCC by EFNARC (2000) with regard to passing ability is between 0.8 and 1.0. Therefore, all specimens for this study satisfied the acceptance criteria by The European Guidelines, 2005 for SCC.

Compressive Strength of SCC

Compressive strength development of SCC containing RCA and normal SCC is shown in Figure 1 (a-c).

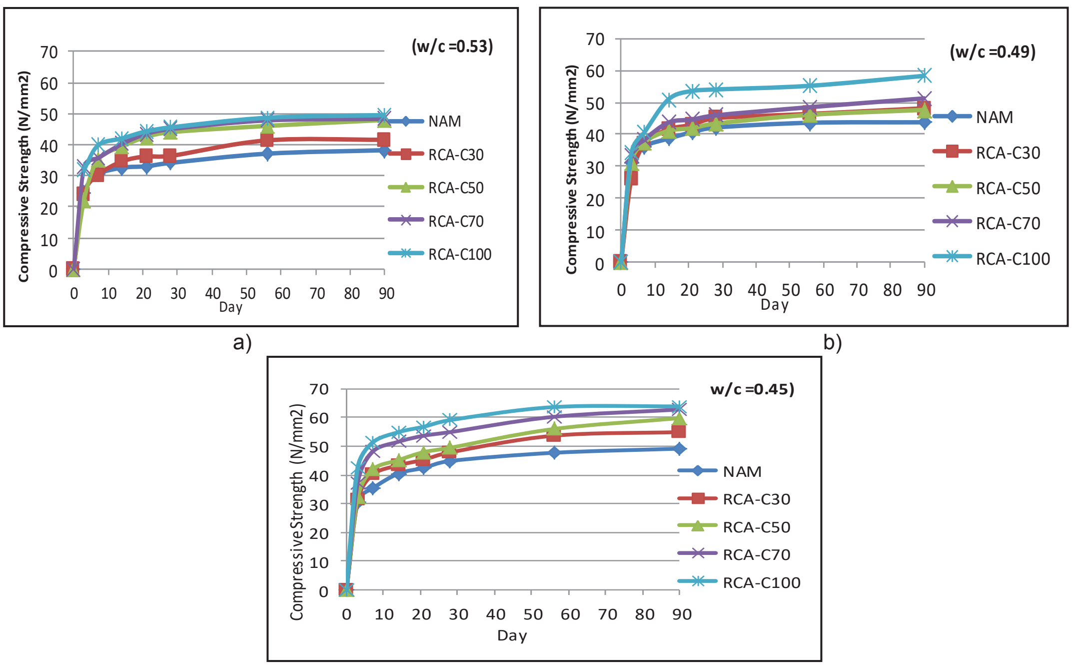

Figure 1. Compressive Strength Development of SCC

For each mix of SCC, the trend of strength development of SCC containing RCA is similar to normal SCC. For the same design strength of the SCC containing recycled concrete aggregate mixes show higher compressive strength when compared to the normal SCC mixes.

Based on the results, it can be seen that all the mixes managed to attain the 28 days design target strength of 30 N/mm^2(w/c=0.53), 35 N/mm^2 (w/c=0.49) and 40 N/mm^2 (w/c=0.45) respectively. From the compressive strength result, all the samples of compressive strength of SCC are achieving the target of characteristic strength at the age 28 days.

Higher value of compressive strength of the SCC is achieved by RCA against normal SCC due to two main factors which are shape and texture of recycled aggregate and its high water absorption by RCA as compared the aggregate to natural granite stone. The angular shape and rough texture are to create a better bond strength than natural aggregates. In addition, higher water absorption by coarse RCA is due contain of attached old mortar. In general, it reduced the effective water cement ratio mixture of SCC-RCA, resulting better paste quality compared to normal SCC. The result is more closely cement particles and hydration process and the production of cement gel together are faster and stronger and thus produce higher compressive strength and the faster increase at an early age concrete.

Rapid Chloride Permeability Test of SCC

In this study, the parameter to be considered as a measurement in chloride permeability is charge passed in coulomb unit. This is because the chloride permeability of concrete face will produce a higher charge passed if the concrete contains many pores.

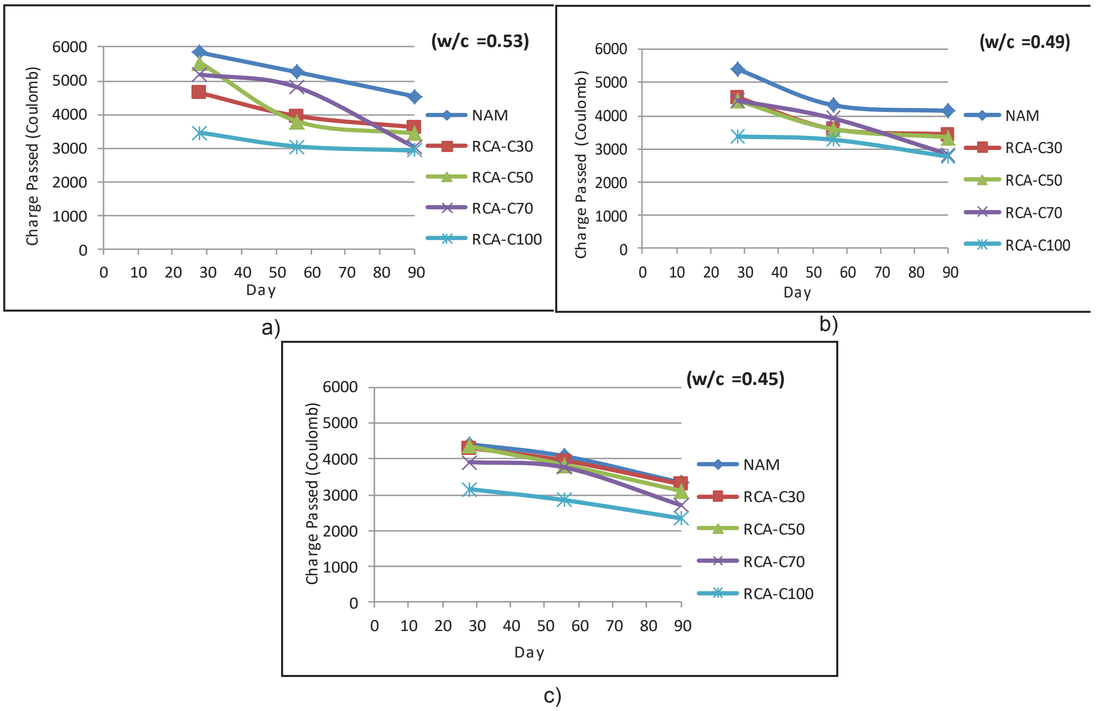

Figure 2. Rapid Chloride Permeability Test of SCC

Rapid chloride permeability of SCC containing RCA and normal SCC is shown in Figure 2 (a-c). For each mix of SCC, the trend of rapid chloride permeability development of SCC containing RCA is same normal SCC. For the same design of the SCC containing recycled concrete aggregate mixes show lower charge passed in term of coulomb as compared to the normal SCC mixes.

From the rapid chloride permeability result, all the samples of rapid chloride permeability of SCC can be categorised as moderate at the age 90 days. Against the SCC mixture, it was found that the SCC with 100% of RCA showed lower charge passed (columb) than other normal SCC mixtures.

This indicates that the hydration process of cement and waste paper sludge ash in SCC-RCA begins to slow and the rate of decrease in chloride permeability is less than normal SCC.

Shahul Hameed et al. (2012) stated the more permeable the concrete, the higher the coulombs; the less permeable the concrete, the lower the coulombs.

Based on the above analysis, it can be concluded that the use of recycled aggregate will provide advantage to the chloride impermeability of normal SCC. Modani and Mohitkar (2014) stated that recycled aggregate can be effectively in the production of SCC without any significant reduction in strength and durability.

CONCLUSIONS

1) The compressive strength of SCC containing RCA increases as the percentage of RCA replacement increases.
2) The SCC containing RCA and WPSA shows lowercharge passed of rapid chloride permeability compare to normal SCC. When the compressive strength is increasing. The charge passed is decreasing.
3) The use of RCA in SCC provide added value in term of strength and durability.

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GUIDE TO AUTHORS

Aims and Scope:

The Malaysian Construction Research Journal (MCRJ) is the journal dedicated to the documentation of R&D achievements and technological development relevant to the construction industry within Malaysia and elsewhere in the world. It is a collation of research papers and other academic publications produced by researchers, practitioners, industrialists, academicians, and all those involved in the construction industry. The papers cover a wide spectrum encompassing building technology, materials science, information technology, environment, quality, economics and many relevant disciplines that can contribute to the enhancement of knowledge in the construction field. The MCRJ aspire to become the premier communication media amongst knowledge professionals in the construction industry and shall hopefully, breach the knowledge gap currently prevalent between and amongst the knowledge producers and the construction practitioners.

Articles submitted will be reviewed and accepted on the understanding that they have not been published elsewhere. The authors have to fill the Declaration of the Authors form and return the form via fax to the secretariat. The length of articles should be between 3,500 and 8,000 words or approximately 8 – 15 printed pages (final version). The manuscripts should be written in English. The original manuscript should be typed one sided, single-spacing, single column with font of 11 point (Times New Roman). Paper size should be of Executive (18.42 cm x 26.67 cm) with 2 cm margins on the left, right and bottom and 3 cm for the top. Authors can submit the manuscript:

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CODIFICATION AND APPLICATION OF SEMI-LOOF ELEMENTS FOR COMPLEX STRUCTURES

Ahmad Abd Rahman[1,2], Maria Diyana Musa[2] and Sumiana Yusoff[2]
[1]Department of Quantity Surveying, Faculty of Architecture, Planning and Surveying, Universiti Teknologi MARA, Sarawak, Malaysia
[2] Institute of Ocean and Earth Sciences (IOES), University of Malaya, Malaysia

Abstract (Arial Bold, 9pt. Left and right indent 0.64 cm.)
Damage assessment …… ……(it should be single paragraph of about 100 – 250 words.)

Keywords: *Finite element analysis; Modal analysis; Mode shape; Natural frequency; Plate structure*

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Heading 2 (Arial Bold + Lower Case, 11pt)

Heading 3 (Arial Italic + Lower Case, 11pt)

Body Text: Times New Roman, 11 pt. All paragraph must be differentiated by 0.64 cm tab.

Units: All units and abbreviations of dimensions should conform to SI standards.

Figures: Figures should be in box with line width 0.5pt. All illustrations and photographs must be numbered consecutively as it appears in the text and accompanied with appropriate captions below them.

Figures caption: Arial Bold + Arial, 9pt. should be written below the figures.

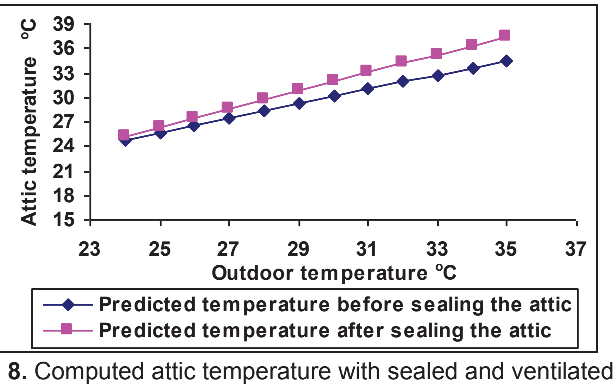

Figure 8. Computed attic temperature with sealed and ventilated attic

Tables: Arial, 8pt. Table should be incorporated in the text.

Table caption: Arial Bold + Arial, 9pt. Caption should be written above the table.

Table Line: 0.5pt.

Table 1. Recommended/Acceptable Physical water quality criteria

Parameter	Raw Water Quality	Drinking Water Quality
Total coliform (MPN/100ml)	500	0
Turbidity (NTU)	1000	5
Color (Hazen)	300	15
pH	5.5-9.0	6.5-9.0

(Source: Twort et al., 1985; MWA,1994)

Reference: Times New Roman, 11pt. Left indent 0.64 cm, first line left indent – 0.64 cm. **Reference should be cited in the text as follows:** "Berdahl and Bretz (1997) found…" or "(Bower et al., 1998)". References should be listed in alphabetical order, on separate sheets from the text. In the list of References, the titles of periodicals should be given in full, while for books should state the title, place of publication, name of publisher, and indication of edition.

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Contents

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