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

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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.

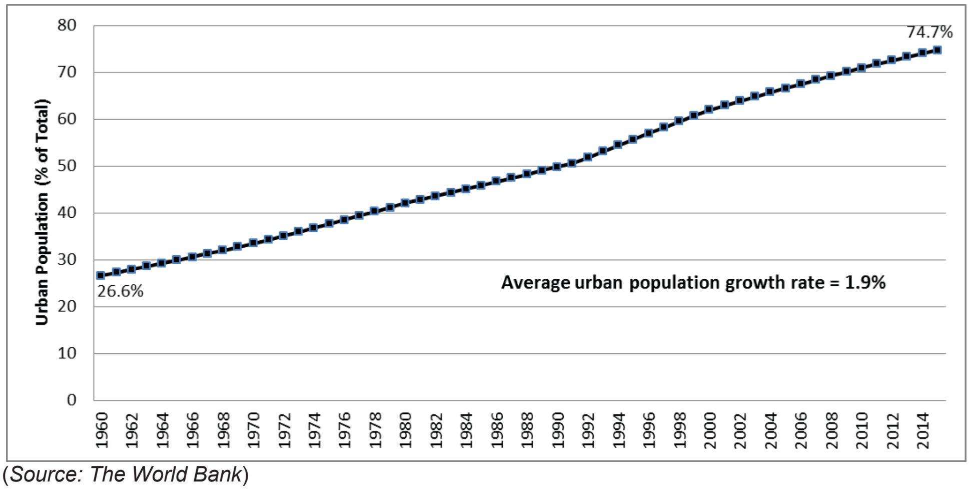
Keywords: *passive design, affordable housing, high performance building, tropical country*

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.

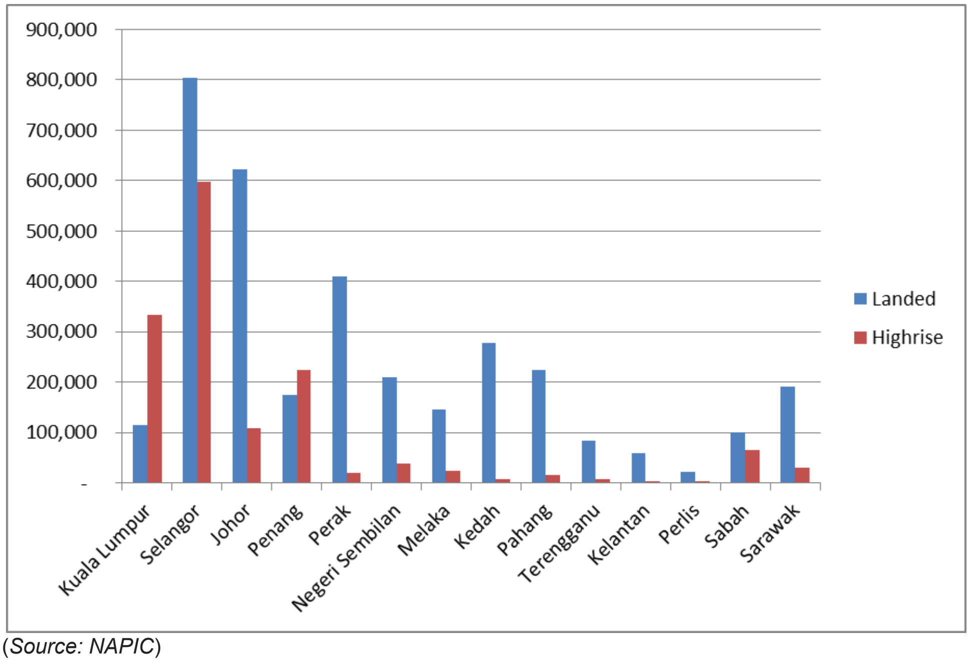
As in many other Asian countries, the urban growth in Malaysia has been rapid in the past decades. According to the report titled East Asia's Changing Urban Landscape: Measuring a Decade of Spatial Growth, Malaysia is one of the most urbanized countries of East Asia, with its urban land grew with an 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).



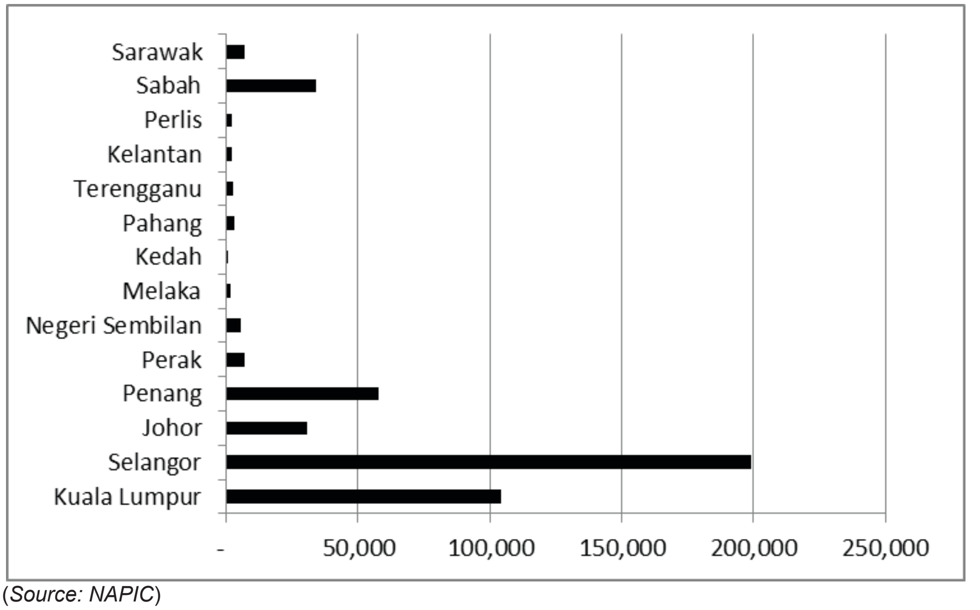
(*Source: The World Bank*)

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.

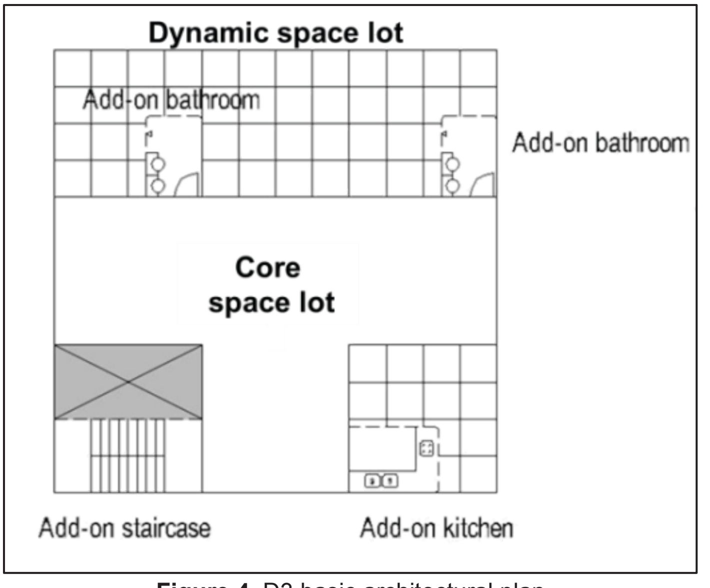


Figure 4. D3 basic architectural plan

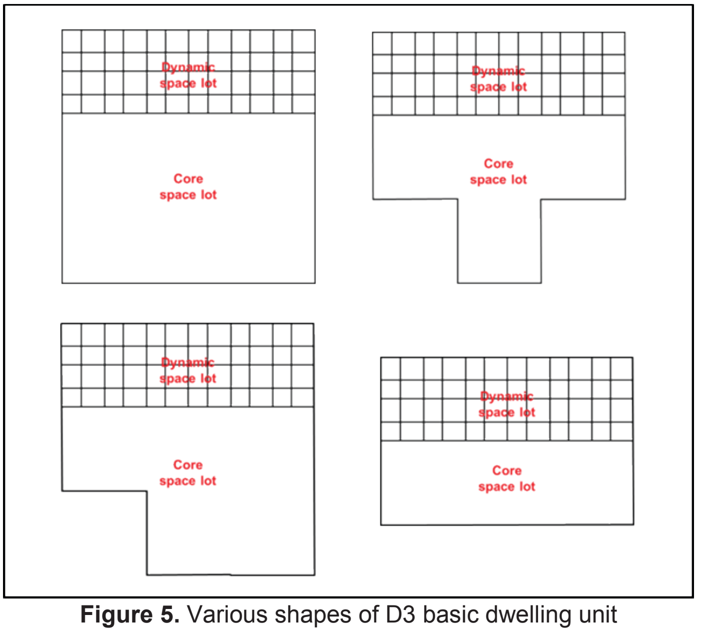


Figure 5. Various shapes of D3 basic dwelling unit

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.

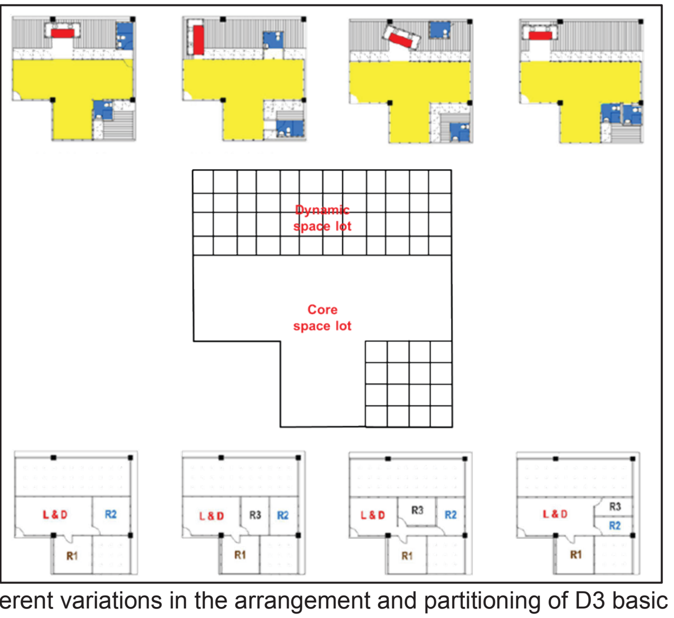


Figure 6. Different variations in the arrangement and partitioning of D3 basic dwelling unit

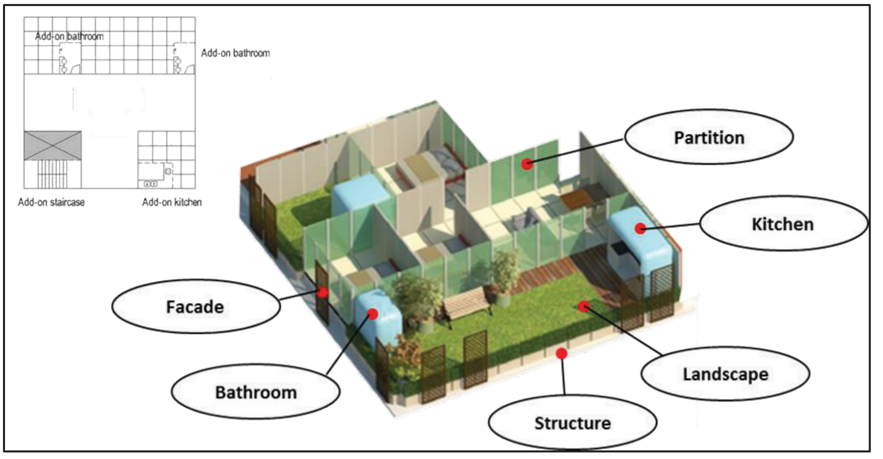


Figure 7. D3 independent building systems

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.

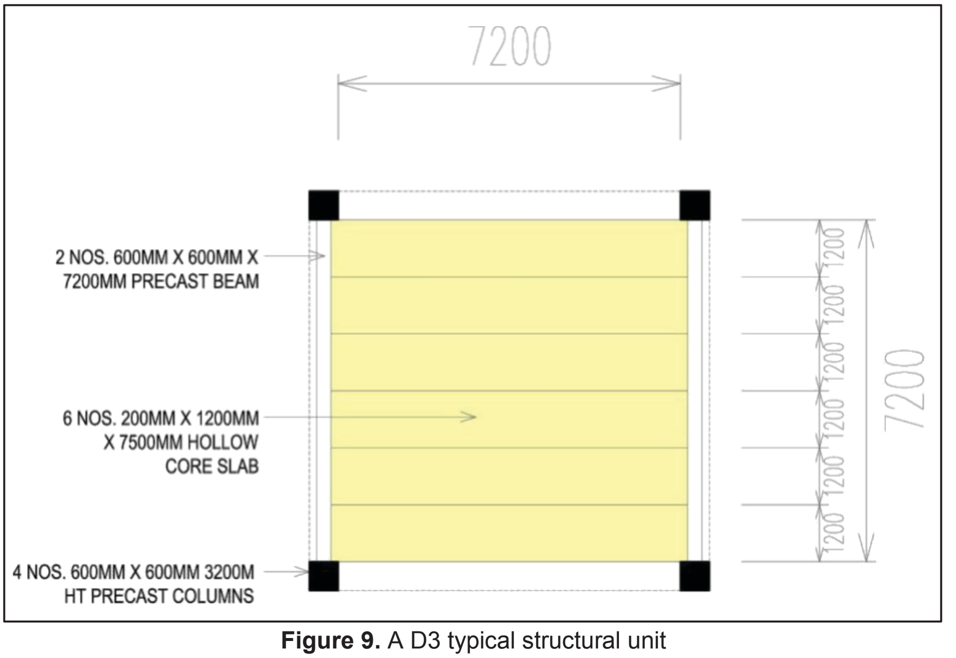


Figure 9. A D3 typical structural unit

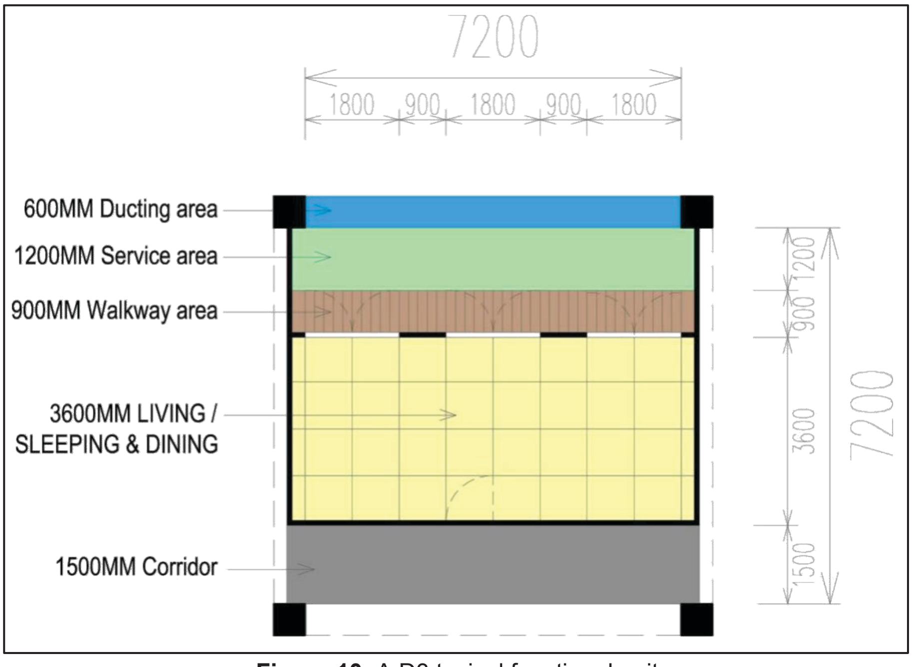


Figure 10. A D3 typical functional unit

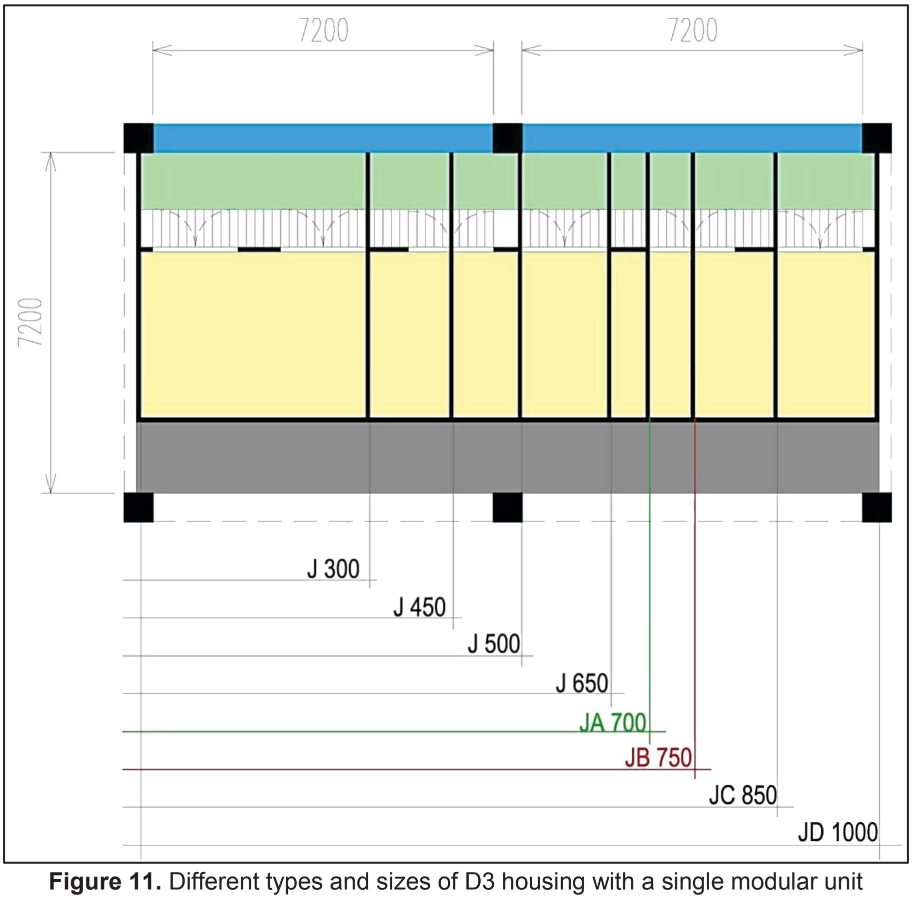
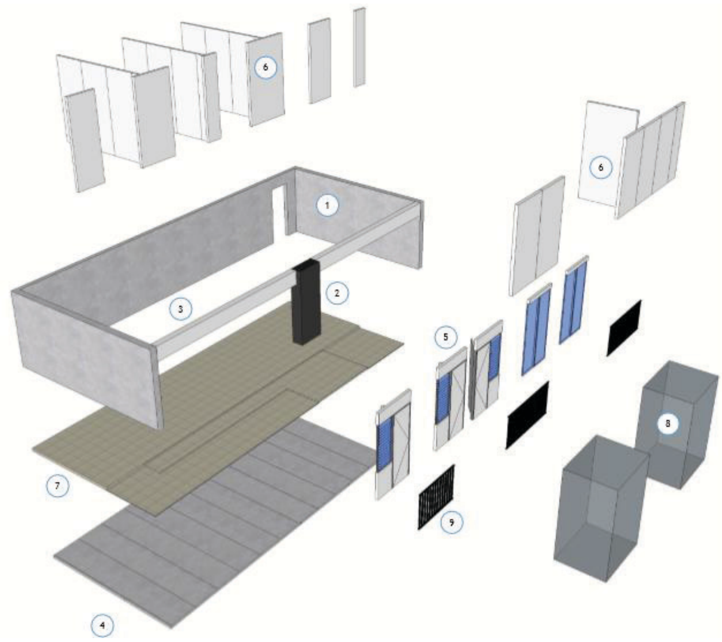


Figure 11. Different types and sizes of D3 housing with a single modular unit

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.

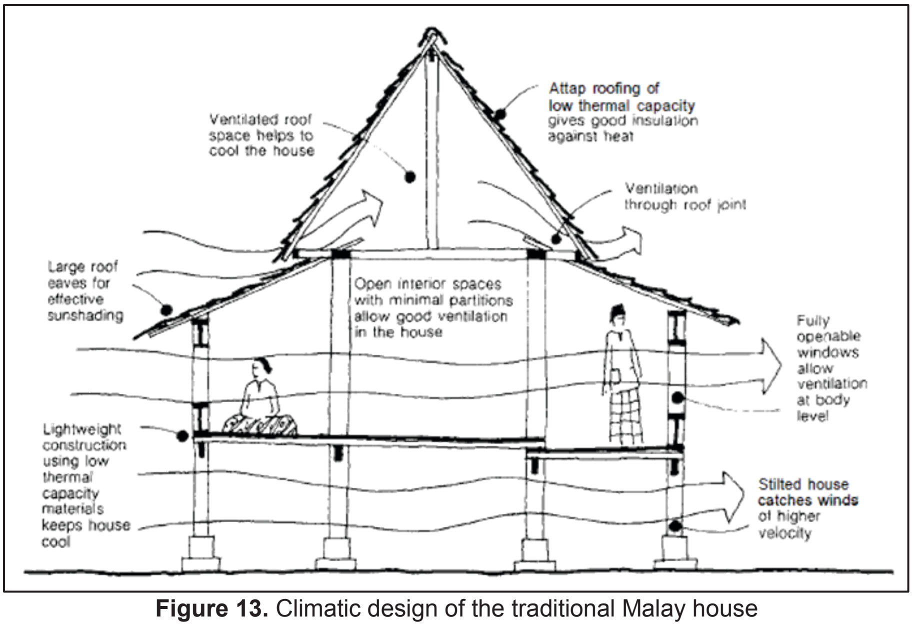


Figure 13. Climatic design of the traditional Malay house

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.

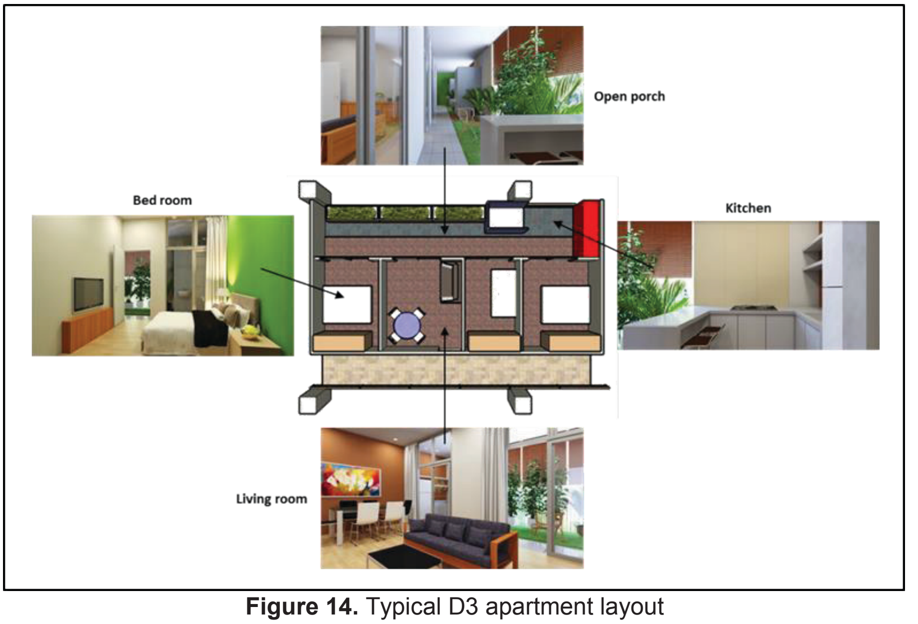


Figure 14. Typical D3 apartment layout

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).

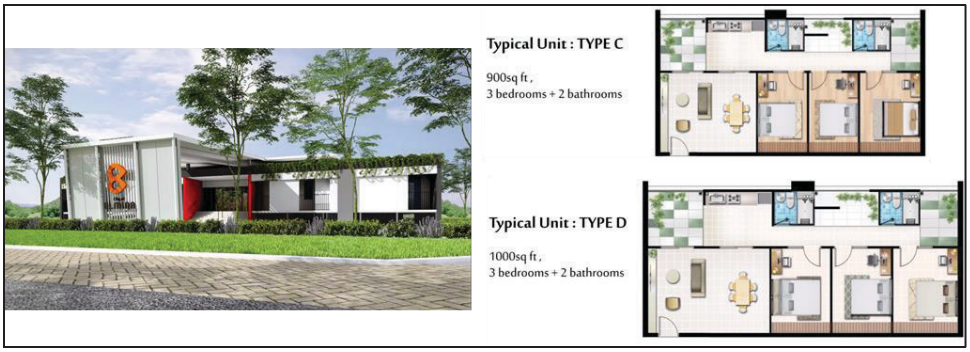


Figure 15. D3 prototype gallery

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 out-grow 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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