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Development of Design Optimization for Smart Grid (DOfSG) Framework for Residential Energy Efficiency via Fuzzy Delphi Method (FDM) Approach

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Abstract: The smart grid revolution has benefited many sectors but the potential for design optimization among residential units has yet to be explored. Despite some researchers having negative perception of house design's association with the smart grid system, there is in fact potential for investigating design attribute optimisation aligned with the smart grid system. As electricity becomes a necessity of the 21st century society, residential dwellers are becoming more dependent on this indispensable source of energy. As such, this paper explains the development of a framework focusing on design optimization for residential units aligned to the smart grid system using the Fuzzy Delphi Method approach. It focuses on the significant smart grid components linked to the residential sector incorporating key design attributes for energy optimization purposes. The proposed framework denoted two main components of residential design optimization, depicted as indoor and outdoor parameters with its subsequent attributes further categorised into main and detailed components. Twelve design parameters were found to be substantial for the DOfSG development, intended to provide useful guide for aligning residential design towards the smart grid system in Malaysia.

Keywords: Smart grid, residential design, energy optimized design, framework development, Fuzzy Delphi Method (FDM)

1. Introduction

Energy efficiency is critical in residential building improvement, delivering several benefits to both homeowners and society. Thus, it is important to overcome the environmental concerns faced today, typically attributed to the substantial global energy consumption increase and its ill-effects to the greenhouse gas emission and climate change. Prioritising energy efficiency is therefore crucial to reduce demand among the individual household energy use. Through eco-friendly practises, installing energy-efficient appliances, and switching to renewable energy sources, dwellers may make a significant impact on global warming mitigation and environmental protection. Energy optimisation increases the

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energy efficiency of residential buildings. Energy waste can be efficiently reduced by homeowners using measures such as improved insulation, energy management systems, and energy-efficient lighting and appliances. These methods cut utility costs, resulting in significant long-term cost reductions. Furthermore, energy-efficient homes have greater resale prices, giving homeowners with long-term financial advantages. The contribution of residential building energy optimisation to energy security is another critical aspect. Homeowners can limit their dependency on external energy sources and lessen the impact of energy price volatility by emphasising energy efficiency and using renewable energy sources. Thus, the increased resiliency enables dwellers to better manage their energy consumption and expenses, resulting in a more stable and secure energy future. Also, energy optimisation enhances occupants' comfort and health greatly. Residents can make their living spaces more comfortable by using energy-efficient building practises such as installing appropriate insulation, ventilation, and cooling systems. Effective insulation for cooling purposes can result in year-round indoor comfort as well efficient operation of air-conditioning. Furthermore, well-designed ventilation systems improve interior air quality, lowering the risk of respiratory problems and generating healthier living environments for residents. Energy optimisation also aligns with regulatory standards and sustainability goals. Numerous countries and areas have adopted building rules and laws that emphasise energy efficiency and the use of renewable energy in residential construction. In the Malaysian context, there are several guidelines and sustainable tools to follow that is currently voluntary but helps to achieve energy optimization and contribute to the broader societal sustainability goals. Hence, residential energy optimisation is therefore critical for addressing environmental concerns, making economic savings, maintaining energy security, improving comfort and health, and complying with regulations. By embracing energy-efficient practises and implementing renewable energy solutions, homeowners can help mitigate climate change, reduce energy waste, and create a more sustainable future for themselves and future generations.

1.1 Design Optimization in the Advent of Smart Grid Systems

Residential design optimization plays a crucial role in the advent of smart grid systems due to several reasons. Smart grid systems are designed to optimise energy consumption and reduce waste. In addition, optimisation of residential design ensures that homes are designed and outfitted with energy-efficient features, such as properly designed insulation, energy-efficient appliances, smart thermostats, and LED illumination. These design considerations aid in reducing energy consumption, resulting in lower energy expenditures and a smaller carbon footprint. Smart grids enable demand response programmes in which consumers can modify their electricity consumption based on real-time pricing and grid conditions. Optimising residential design aligned to the smart grid incorporates smart technologies, such as smart metres and home energy management systems, allowing homeowners to effectively monitor and manage energy consumption. Incorporating these technologies enable homeowners being part of the smart grid’s demand response programmes to shave peak demand and foster grid stability. Furthermore, smart grid facilitates renewable energy (RE) sources like solar panels and wind turbines which has seen significant increase since the introduction of Feed in Tariffs (FiT) and Net Energy Metering (NEM) by SEDA (Sustainable Energy Development Authority) and EC (Energy Commission) (SEDA, 2021a, 2021b). Residential design optimisation considers solar orientation, shading analysis, and utilisation of roof space to maximise the potential for renewable energy generation. As such, incorporating these design elements, homes can generate renewable energy and potentially offset a substantial portion of their electricity usage, contributing to a greener grid. In the recent future, energy storage technologies, such as batteries, are essential to maximising the benefits of smart grid systems. Optimising residential design considers the incorporation of energy storage systems via storing excess energy during off-peak hours and discharging it during times of peak demand or grid disruptions, homeowners can reduce their reliance on the grid and improve grid stability. Proper design optimisation maximises the effectiveness of energy storage systems by ensuring their efficient installation and management.

1.2 What is the Purpose of This Paper?

This paper intends to develop a novel framework for optimising the residential design for the smart grid system, specifically for achieving residential energy efficiency. Utilising recent technologies and optimisation strategies, this research aims to provide useful from guideline for alleviating rising residential sector energy demand. Core aspects of this paper is discussed in three sections: the development of a Design Optimisation for Smart Grid (DOfSG) framework, residential energy efficiency and the utilisation of the Fuzzy Delphi Method (FDM) in its development. DOfSG framework seeks to provide a systematic approach to design homes in accordance with the SG system, which in turn enable effective optimisation of its function to intelligently manage residential energy distribution, consumption, and generation. FDM incorporates systematic decision-making techniques from expert panels through fuzzy logic and Delphi method. In other words, FDM captures and integrate expert knowledge, experience and opinions from various stakeholders involved in smart grid projects and residential development, by taking uncertainties and linguistic preferences into account. The overall objective of this paper is to propose a comprehensive framework that employs optimisation techniques and the Fuzzy Delphi Method to improve residential design towards achieving energy efficiency via smart grid systems. The goal is to make a significant contribution to the field of residential design by considering the requirements and limitations associated with residential energy consumption and optimising the design process accordingly.

2. Literature Review

The smart grid (SG) is a digital power infrastructure that facilitates effective and dependable energy management to meet the requirements of today's increasingly electricity-reliant society. Despite the presumed dissociation between smart grid systems and house design, several research studies point towards house design feature optimisation based on the SG system, that is deemed promising for residential energy optimisation (Aduda, 2018; A. D. Georgakarakos et al., 2018). The National Institute of Standards and Technology (NIST) introduced an NIST Framework and Roadmap for Smart Interoperability Standards, intends to standardize the different components, technologies and stakeholders involved in the complex, ubiquitous and ever evolving smart grid system. Within the framework, a smart grid conceptual model was developed to address the interoperability challenges across different systems and technologies. The NIST Smart Grid conceptual model illustrates the fundamental restructuring of a system that is more reliant on distributed resources, as well as the technological and platform-driven capabilities emerging in the Customer and Distribution Domains. It also denotes interoperability between several smart grid components brought about by the new smart grid system merging new technologies and intelligent systems to improve the efficiency, reliability, and sustainability of power generation, transmission, and distribution. Two important components of the SG system related to this research are distributed energy generation and demand response, which specifically focus on optimising electricity consumption instead of production. (Gopstein et al., 2021). As the new digital electricity grid, SG operations are affected by the myriad connected system, networks, devices, applications and components that work together within the SG environment. Within the residential sector itself, a home unit interacts with the SG system in many ways as shown in the figure below.

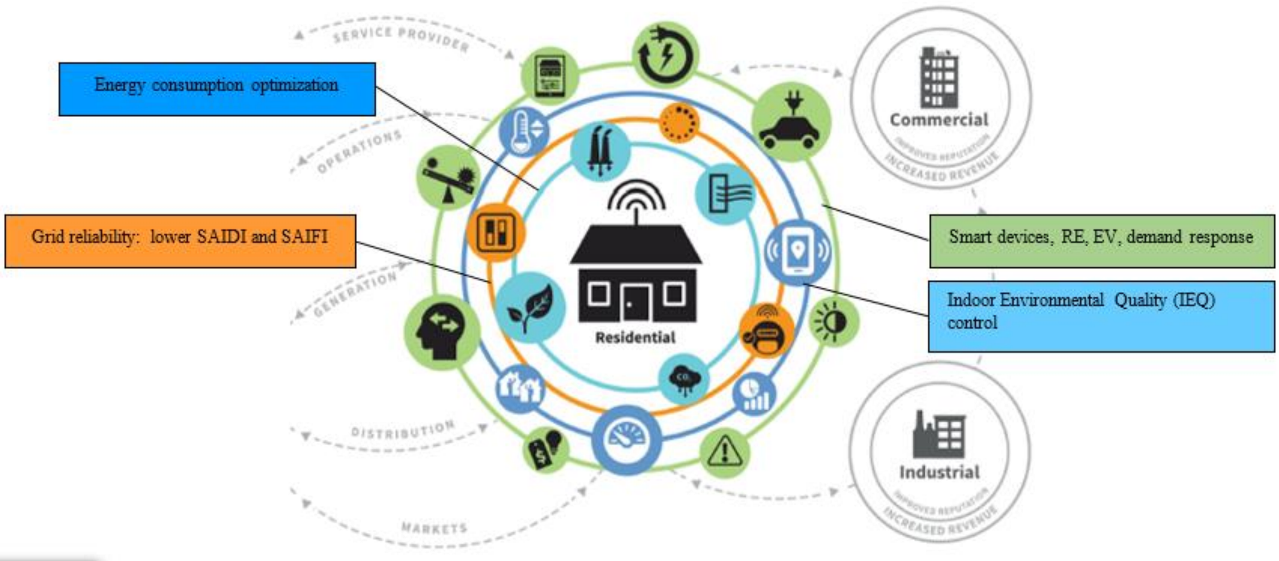

Fig. 1 - Interconnectivity of a residential unit with the smart grid system. Modified from (Gopstein et al., 2021)

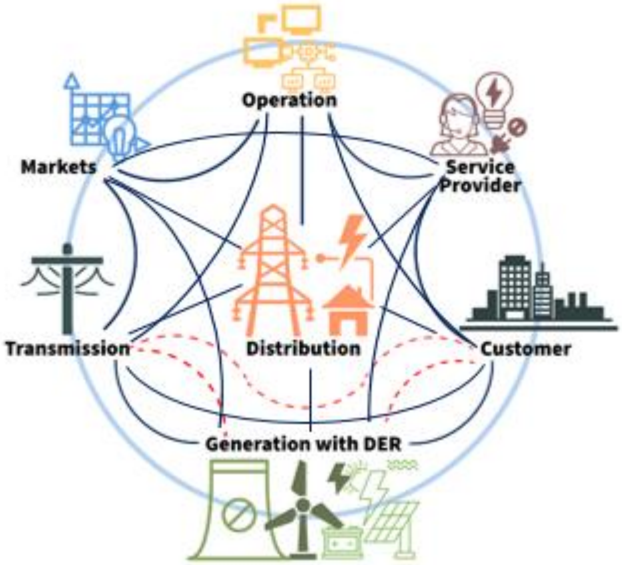

Fig. 2 - NIST Smart Grid Conceptual model. Modified from (Gopstein et al., 2021)

The complexity of SG system is represented in the NIST SG conceptual model as shown in Fig.2 above which identifies and categorizes the different SG components. The conceptual model is divided into 7 critical components of the smart grid system: distribution operation, service provider, customer, Generation including DER, transmission and markets. The NIST smart grid model is a useful framework for categorising and analysing the various components and systems that comprise this complex infrastructure, whereby suitable SG components for this research shall be further investigated. Each SG components are investigated and given rating based on their significance to this research. Table 1 below depicts relevancy of the different smart grid components to this research. Utilising their respective functions, characteristics and detailed data, significant domain for this research were given three types of its significance, that shall be integrated into the DOfSG framework. The three level ratings are high – given special priority for detailed investigation, medium – second level of domain to be included (but not all items), and low- some items may be included with special selection.

2.1 Review of Any Existing Optimization Framework Based on the Smart Grid System

Building design optimisation frameworks are crucial to achieving energy-efficient buildings by reducing energy consumption and promoting sustainability. This paper approach to the effectiveness, limitations, and defining characteristics of existing building design optimisation frameworks for energy consumption optimisation. Earlier Smart Grid Optimised Building (SGOB) model was proposed by Georgakarakos (2018). This SGOB model combines the characteristics of smart, active and zero-energy building concept that can provide information for functional work environment, good return to its owner and offer flexibility to service provider (electricity utility). In other words, an SGOB can be considered as delivering its service responsibilities to occupants while lowering the operational expenses and footprint for its owner, all while actively engaging with the electrical provider and maximising the utilisation of available resources. Based on this model, updates were made to include SG components into the SGOB conceptual model as shown in Fig. 3 . It aims to identify potential and critical SG components for consideration to improve house unit development in accordance with the SG system. The establishment of the smart grid component into the SGOB has far-reaching implications for residential design, designated through energy efficiency and environmental friendliness. Power generation, distribution, and consumption in homes are all being altered by this technologically enhanced power system. This innovative system makes use of cutting-edge communication infrastructure and digital technology to enable real-time energy monitoring, management, and optimisation of energy consumption(Judge et al., 2022; Khan et al., 2021; Wang, 2016). The SG system offers significant advantages to the residential sector. It promotes energy efficiency by providing accurate data on household energy consumption and empowering them to make informed decisions to reduce unnecessary usage. This results in reduced energy costs and environmental impact. Additionally, the system facilitates demand response programmes, enabling households to modify their electricity consumption during periods of peak demand, thus balancing the load and preventing outages. The smart grid system enables the seamless integration of sustainable energy sources like solar and wind, hence reducing reliance on conventional power resources.

Table 1 - Significant SG components to research

Smart Grid components	Annotation	Relevance to research
Distribution	Deliver power from transmission to end users. Integrating distributed energy resources (DER), maintaining grid resilience, controlling power flow.	Medium
Operation	Operation domain manages and controls smart grid infrastructure. It monitors, manages, and optimises power generation, transmission, and distribution. Real-time data, complex analytics, and control systems characterise this domain. It describes grid monitoring, defect detection, outage management, and grid optimisation, which make the smart grid reliable and efficient.	Low
Service Provider	Service providers supply energy services to the end users. It covers residential, commercial, and industrial power and service delivery. Also, it oversees demand response programmes under price signals to lower peak demand, engage consumers with energy management information, tools, and options. This is realised through smart metres, real-time energy consumption information, energy efficiency programmes, and other services. Smart meters enable accurate billing, implement time-of-use (ToU) and dynamic pricing. Service provider domain grid management and control systems ensure smart grid infrastructure stability, dependability, and security. This entails monitoring grid conditions, managing energy flows, coordinating generation and distribution, and responding swiftly to outages and disturbances. Rooftop solar panels, energy storage systems, electric cars, and microgrids integrated into the SG system is managed by the service provider domain and optimise their operations to maximise system efficiency. Service providers facilitate energy transactions, grid dependability, and customer energy management between smart grid infrastructure and end-users.	High
Customer	The customer domain is central to the smart grid paradigm, emphasising end-users' active participation in managing their energy consumption. Smart metres, home automation systems, and demand response programmes are examples of technology that enable users to monitor and control their electricity usage. This domain research expands our understanding of the tools and mechanisms that allow customers to make educated decisions about their energy usage, promote energy efficiency, and support grid stability through demand response.	High
Generation with DER	The generation with DER domain represents SG component on power production. It includes conventional power generation sources such as coal, natural gas, and nuclear, as well as renewable sources such as wind and solar. Understanding the various energy mixes that contribute to the smart grid's power supply and the integration of renewable energy sources requires a thorough understanding of this domain.	High
Transmission	Efficient and dependable electricity transfer from power plants to local distribution networks over vast distances. It is made up of high-voltage transmission lines, substations, and related equipment. The infrastructure allows power transfer across enormous geographical areas, as well as the problems involved in maintaining grid stability and reliability.	Low
Markets	The market domain comprises smart grid economics, including electricity buying, selling, and pricing. This domain promotes energy efficiency, renewable energy, and stakeholder participation. Understanding market dynamics, promoting renewable energy integration, enabling grid flexibility, and rewarding consumer behaviour towards sustainable energy consumption require this domain. In other words, this domain describes the organisational structures, service frameworks, and collaboration mechanisms that support smart grid functions such as grid maintenance, cybersecurity, system resilience, and customer support.	High

It also facilitates the incorporation of electric vehicles (EV) through the efficient management of charging infrastructure and the optimisation of vehicle charging to utilise renewable energy generation. Additionally, the system encourages the installation of sophisticated energy management systems, enabling householders to control and automate various aspects of energy consumption to improve efficiency. Therefore, towards achieving cleaner and resilient energy future, the smart grid system enables residential sector improvement through sustainability, grid stability, cost savings and offer greater control over their energy consumption.

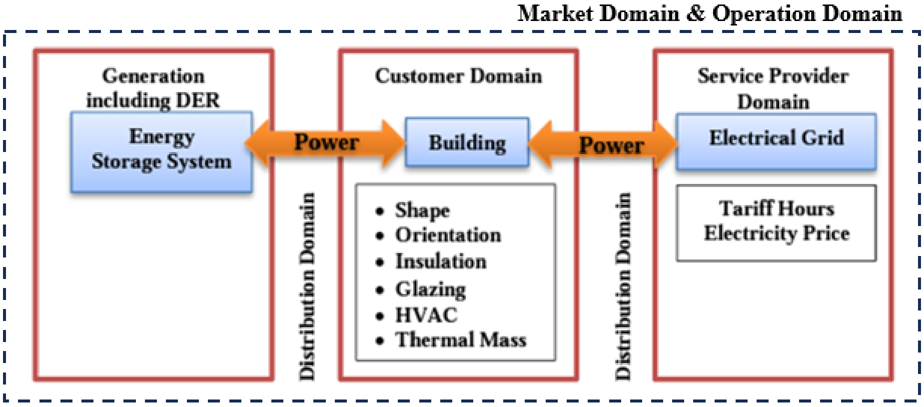

Fig. 3 - Adapted SGOB model
(Ahmad Haqqi Nazali et al., 2021; Georgakarakos et al., 2018)

Fig. 3 above denotes integration of the SGOB model with the significant SG components and its purpose in the SGOB model. As part of the SG development, RE integration presented challenges to grid stability but the energy storage integration has been viewed as an optimal solution (Judge et al., 2022). Therefore, energy storage system makes up part of the SGOB model, contributing stability to the grid due to increasing RE and the proliferating and rising distributed energy resources (Morvaj et al., 2016). Under the customer domain, building becomes the focus of this research as it represents the resident's premises. As such, energy related factors are considered as an important element affecting energy demand therefore becomes part of the model. Also, Table 1 depicts resident's participation in the SG system through smart meters, home automation system and demand response program (DR). These technologies allow customers make educated energy demand decisions, promote energy efficiency and support grid stability through DR. Service provider domain in the SGOB model links up with the residential unit through the smart meter, supplying energy price and supplemental data for DR programme. In between these domains is the distribution domain, while the market domain provided the platform for electricity trade and the operation domain controls and ensures electricity supply to the end users.

Another research-significant framework was proposed by Morvaj et al (2016), that investigated combination for optimal design and operation of distributed energy system, that has seen a substantial increase in the SG system. His proposed framework accounted for grid constraints and building energy use and the high level of RE integration has impacted the optimizing strategies. Nevertheless, the framework presented an optimal approach to allow up to 40% RE integration into the existing grid system without any substantial upgrades. Thus, the framework identifies aspects of building energy use that is perceived critical for consideration in the development of DOfSG framework for this research. Remarkably significant for proper design and determining operation schedule for DES, its framework structure shows possible implementation in this research. The fraction on building energy input poses interesting portion for DOfSG.

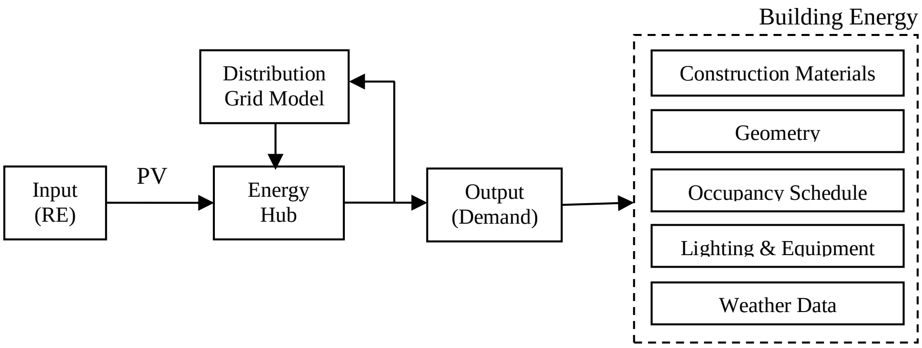

Fig. 4 - Optimization framework for distributed energy system ((Morvaj et al., 2016)

2.2 Explanation of The Proposed Framework for Optimizing Smart Grid Systems in Residential Buildings

Following the SGOB conceptual model and the optimization framework as discussed earlier, this paper investigates the potential, limitations and defining capabilities of existing building design optimizations framework for energy use optimizations. There are, in fact other frameworks such as the ASHRAE Standard 90.1, passive design strategies, net-zero energy buildings, active buildings and other locally developed guidelines that focuses on energy efficiency strategies. While these standards and frameworks have provided extensive energy efficiency, it has not considered the Smart Grid System as an opportunity for further optimization. Smart technology development linked to the SG system that is incorporated into the housing unit can be utilised for energy demand reduction, particularly through automation that is enhanced by design integrated smart techs. As their implementation and integration may be seem capital intensive, proper selection of the different techs for integration may be economically advantageous to its users. Effective in certain circumstances, their applicability may be limited to certain residents or housing types but coordination with utility companies may alleviate this limitation. Thus, the different constructs and items for the DOfSG development is crucial for designers, developers and homeowners to decide the various attributes for gaining benefits from the SG system. Building design optimisation is critical to developing energy-efficient buildings that minimise environmental impact while preserving occupant comfort and well-being.

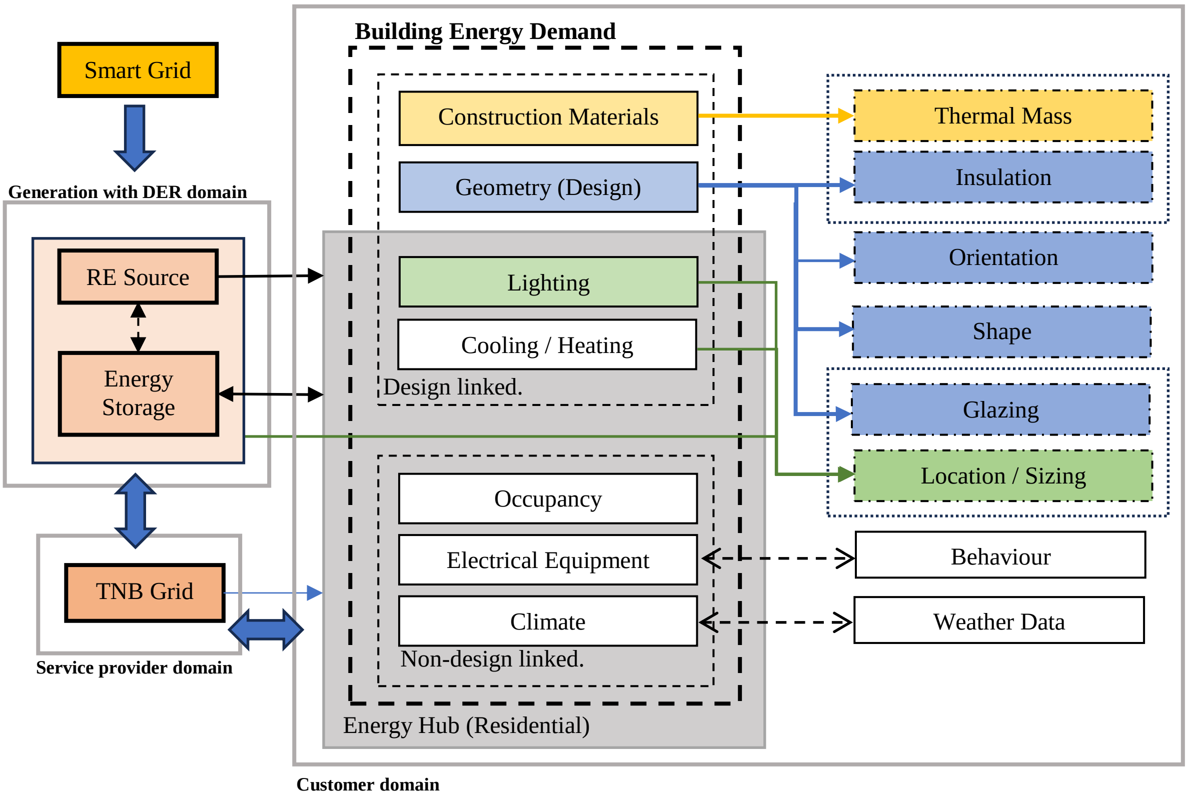

Fig. 5 - Proposed Design Optimization for Smart Grid (DOfSG) framework

2.3 Explain What is DOfSG

The initial DOfSG framework (refer Fig. 5) development aims to assist architects, engineers, and designers in the creation of sustainable buildings. In view of this, the framework provides outlines for identifying critical factors for design optimization attributes to create an energy optimised building in accordance with the SG system. It allocates the different building energy demand attributes under the significant SG domain as denoted by the NIST Smart Grid model (Gopstein et al., 2021). The customer domain accounts for a substantial portion of this framework due to its focus on the residential unit, which is at the centre of this study. The customer domain connects to the DER domain and the Service Provider domain. According to various literature and research, the integration of RE sources is an essential component of the SG, while energy storage has become a critical enabling component to assure grid stability due to the widespread presence of RE (A. D. Georgakarakos et al., 2018; Marczinkowski & Østergaard, 2018; Rezaeimozafar et al., 2022). According to the SG conceptual model, RE sources and energy storage are viewed as large-scale installations in the SG system. The grid connected RE generation and energy storage system is connected directly to the grid and is identified as a virtual power plant in the grid monitoring service. (Hesse et al., 2017; Marczinkowski & Østergaard, 2018)

Nonetheless, the residential unit may be outfitted with both RE and energy storage on its premises, but its purpose and function differ from large-scale installations as it is intended for domestic use (Ma & Li, 2020). External smart grid components from other domains can be linked to the residential unit's energy hub via a smart meter within the domestic premises. Other factors influencing building energy demand outside the energy hub include construction materials and geometry. Despite this, it is used in the installation of RE equipment, energy storage, and other SG-connected smart devices that contribute data to the energy hub, commonly known as the Home Energy Management System (HEMS). (Ostovar et al., 2022). The energy hub is separated into two parts: design-related (lighting and heating/cooling) and non-design-related (occupancy, electrical equipment, and climate). The energy consumption of electrical equipment is affected by occupant behaviour. Furthermore, cooling or heating equipment is almost always linked to the surroundings and weather conditions. Home automation, on the other hand, could decrease energy usage using smart technologies (Härkönen et al., 2022). For example, by automating the opening and closing of fenestration and windows, home automation might mitigate excessive consumption, such as prolonged usage of air conditioning for cooling, or engage in initial building cooling through natural ventilation. Home automation is integrated into the energy hub, along with information display and feedback (concerning energy use), to enable inhabitants to make informed decisions about their consumption patterns. Machine learning and artificial intelligence advances will aid in the development of an accurate self-regulating HEMS that learns about its inhabitants' consumption habits, uses real-time energy prices, and strives for high efficiency in the residents' energy demand (Asem Alzoubi, 2022). Some construction material may affect building energy demand, such as the thermal mass material that retains heat causing latent heat release into the building’s interior. Latent heat release causes the interior to become thermally uncomfortable for the occupants. Despite this knowledge, modern homes in Malaysia continues to be constructed using cement and concrete wet work. However, there are modern approach to counter this issue by restricting heat gain (via insulation or vegetation) onto the thermal mass or continuous cooling through natural ventilation. Under the geometry segment, passive design strategies are suggested for building energy efficiency. In the context of this research, building orientation optimizes on only for building cooling but also for integrating solar panel on the building. Proper and integrated design could enhance solar panel efficiency therefore achieve optimal energy conversion. Another critical design factor is the design, sizing and location of glazing which in this research shall concern the daylighting and artificial lighting use in homes. Integrated HEMS and IoT (internet of things) allow autonomous control of lighting and solar gain entering the building that affects indoor thermal comfort (Philip et al., 2022).

In the context of this research, HEMS or the energy hub becomes key in the control of demand response and load management within the SG system. The energy hub enables homeowners to monitor and control their domestic energy consumption. It is developed and designed to provide greater control and efficiency over energy usage, resulting in potential cost savings and environmental advantages. Typically consisting of a myriad of connected smart devices, sensors and software that collects and analyse energy consumption data from various home appliances and systems, including heating and cooling, lighting, and appliances. The energy hub supplement data for demand response program that is used by utility companies to manage peak electricity demand. By incentivizing consumers to voluntarily reduce their energy consumption when demand exceeds supply, these programs seek to alleviate strain on the power grid and prevent blackouts and brownouts. The integration of energy hubs and demand response program enables homeowners to actively partake. During critical peak loads, demand response event activates the program to energy hub may autonomously adjust energy demand based on user preferences or predefined settings. It may temporarily reduce or transfer energy consumption from non-essential appliances or systems, such as by temporarily reducing the use of air conditioning or hot water heaters.

2.4 Description of the Methodology for Developing the Framework

The initial proposed DOfSG framework is validated against expert opinions, selected based on their expertise and has involved in residential design and energy efficiency or smart grid projects. Utilising this strategy for framework verification, this research proposes to adopt Fuzzy Delphi Method (FDM) in the identification of key design attributes of houses, suitable for DOfSG framework development. FDM is proven by many literatures and research as an important research method in various field, including building design, energy sector and the smart grid (Bui et al., 2020; Mabrouk, 2020; Marlina et al., 2022). FDM provides a systematic method for collecting and analysing expert opinions in the context of smart grid research, where critical items acquired for the development of DOfSG is presented to experts. FDM employs fuzzy logic to support researchers in capturing and quantifying the uncertainty of smart grid components under the various domains proposed by the DOfSG framework. The sequence and strategy for employing FDM in this study are depicted in Fig. 6. The research sequence is divided into two major sections, Initial DOfSG Framework and the Improved DOfSG Framework. Utilising the typical FDM approach, the primary step is to develop a questionnaire based on the initial DOfSG items and constructs. In the initial process in FDM, a pilot survey was conducted on a group of experts, yet in smaller numbers intended to improve the questionnaire set. Two expert panel were selected; one from the design background (architect attached to the academic institution) and the second expert panel appointed from the utility company – Tenaga Nasional Berhad (TNB). Outcome from the expert comments and recommendations were addressed accordingly to create a better version of the questionnaire, that’ll be used in the subsequent FDM process. The experts evaluated whether factors or indicators should be introduced or eliminated in the questionnaire set. FDM process enable expert opinions to be converted into precise empirical numbers to fulfil the objective of this study and generate additional benefits in relation to the decision-making time and money (Bui et al., 2020).

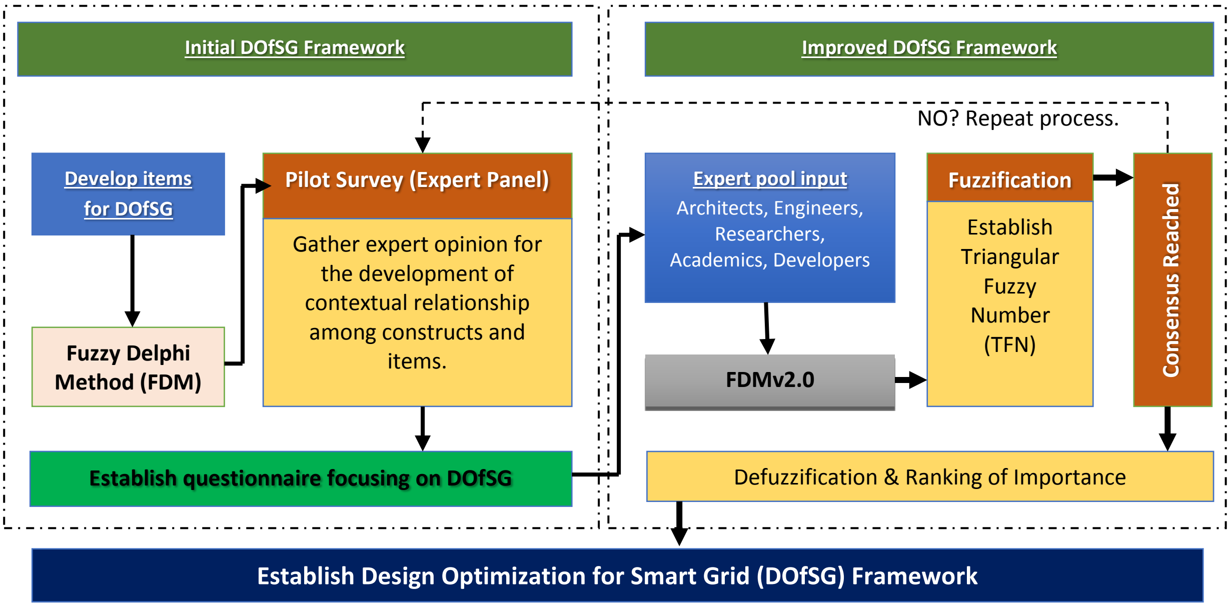

Fig. 6 - Fuzzy Delphi Method (FDM) approach to DOfSG framework development

The questionnaire set contains three main sections: (A) Respondents' demographics data, (B) Smart grid domain / sub domain theoretical framework and, (C)house design parameters. The questionnaire set contains 57 items that were later sent to the selected expert panel, appointed from the two dimensions of the research context: design dimension (house design) and the energy (smart grid) dimension. Eleven (11) expert panels were specially selected for this FDM rounds. The minimum number for expert panel in the FDM process has been discussed widely by several FDM researchers (Mohd Jamil & Mat Noh, 2021). The demographics of the selected expert are summarized in Table 2 below.

Table 2 - Expert panel background

Expertise Category	Expertise Affiliation	Position
Eng	Energy (GLC)	Director, Energy Demand Management Division
Des	Design (Academic)	Deputy VC Universiti Teknologi Malaysia
Eng	SmartGrid (Industry)	Resident Engineer (C&S)
Des	Design (Industry)	Principal Partner
Des	Design (Industry)	Principal Architect
Des	Design (Industry)	Head of Design Management
Eng	SmartGrid (Industry)	Project Management Officer
Eng	SmartGrid (Industry)	Senior Engineer
Eng	SmartGrid (Industry)	General Manager
Eng	SmartGrid (Academic)	Senior Lecturer / Researcher
Eng	Energy (GLC)	Energy Management Engineer

Each question was designed to acquire responses in the form of seven-point Likert scale as shown in the table below (Refer Table 3). According to Mohd Jamil & Mat Noh (2021), seven-point scale is the best to reduce the fuzziness gap between the acceptance value and expert consensus. In addition, both authors have denoted the advantage of the seven-point scale precision in acquiring a more accurate response.

Based on Table 3 and Fig. 7, Triangular Fuzzy Numbers (TFN) enabled the translation of each expert's Likert scale response into a fuzzy score (refer to Table 2 and Fig. 7). There were three values to evaluate for each recorded response: the average minimum value (n1), the most reasonable value (n2), and the highest value (n3). The purpose of TFN was to illustrate the fuzziness or imprecision of an expert's opinion. Given that the Likert scale is a fixed score, it is unable to account for the ambiguity inherent in every opinion (Yusoff et al., 2021). An expert gave the statement "Solar components (BIPV, roof PV, PVSD) are important components for a residential unit connected to the smart grid" scored 7 (highly agree) on the Likert scale. The score is converted to fuzzy scores with minimum, most reasonable, and maximum values of 0.9, 0.9, and 1.0, respectively. It indicated that 90%, 90%, and 100% of experts concur with the statement, respectively. As indicated by the m1, m2, and m3 values, the fuzzy scores were averaged for the Defuzzification process. Based on comments and suggestions from expert panel of the pilot survey, the questionnaire format was too complex and complicated to be understood for the expert respondents. Therefore, in the subsequent expert input rounds the questionnaire was translated into a graphical format as shown in Fig. 8 below. The graphical representation of the questions was given coding number, intended to accommodate database entry into the Microsoft Excel format FDMv2.0 Analysis Template created by Jamil & Mat Noh (2021).

Table 3 - Likert scale mapped to seven-point fuzzy scale representation

Scale	Level of Agreement	Fuzzy Scale
1	Highly Disagree	(0.0,0.0,0.1)
2	Disagree	(0.0,0.1,0.3)
3	Slightly Disagree	(0.1,0.3,0.5)
4	Neutral	(0.3,0.5,0.7)
5	Slightly Agree	(0.5,0.7,0.9)
6	Agree	(0.7,0.9,1.0)
7	Strongly Agree	(0.9,1.0,1.0)

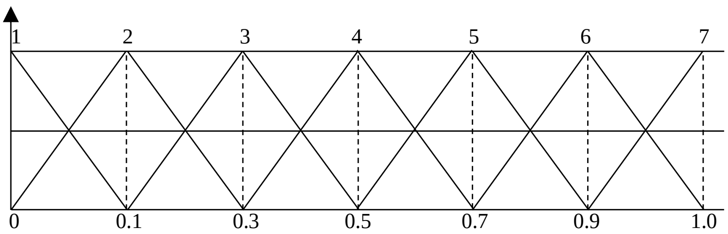

Fig. 7 - Linguistic scale of triangular fuzzy number for defuzzification process
Source: (Mohd Jamil & Mat Noh, 2021; Yusoff et al., 2021)

Due to the FDM process requiring anonymity between the expert's questionnaire rounds, their respective questionnaire interview was conducted individually. An online interview method was carried out using Google Meet for the respective expert panels and each panel was shown the graphical representation via Miro Board that consisted of the questionnaire set. Miro Board provided a suitable platform for synchronous online discussion that enable respondents to intuitively respond to the questions and provided feedback immediately. Experts were also able to provide feedback by writing on the "post-it-note" as a remark for the selected item.

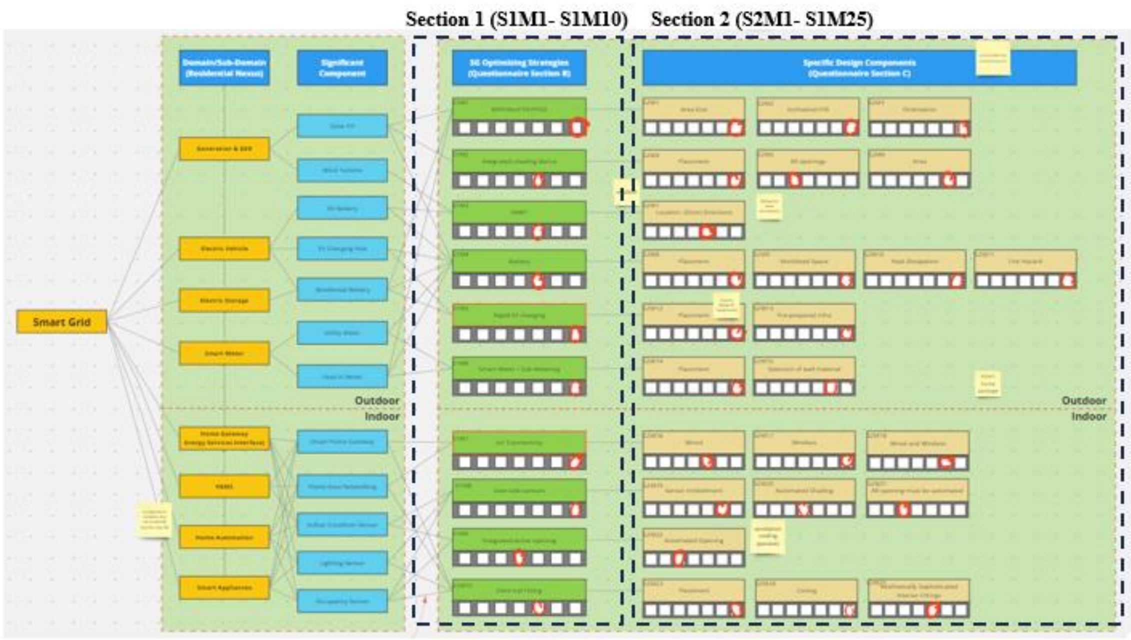

Fig. 8 - Graphical representation of the questionnaire set via Miro Board application with code numberings ***(See appendix for clearer image).***

Table 4 - Summary of questions represented in Miro Board for Section 1, Questions 1-10

Code	Item	Question details
S1M1	BIPV/Roof PV/PVSD	Solar components (BIPV/Roof PV/PVSD) are important components for a residential unit connected to the smart grid.
S1M2	Integrated shading device	Integrated shading device is an important component for a residential unit connected to the smart grid.
S1M3	VAWT	Vertical Axis Wind Turbine (VAWT) is an important component for a residential unit connected to the smart grid.
S1M4	Battery	Battery is an important component for a residential unit connected to the smart grid.
S1M5	Rapid EV charging	Rapid EV charging is an important component for a residential unit connected to the smart grid.
S1M6	Smart Meter / Sub-Metering	Smart Meter / Sub-Metering is an important component for a residential unit connected to the smart grid.
S1M7	IoT Connectivity	IoT Connectivity is an important component for a residential unit connected to the smart grid.
S1M8	User-side sensors	User-side sensors is an important component for a residential unit connected to the smart grid.
S1M9	Integrated active opening.	Integrated active opening is an important component for a residential unit connected to the smart grid.
S1M10	Electrical Fitting	Vertical Axis Wind Turbine (VAWT) is an important component for a residential unit connected to the smart grid.

Table 5 - Summary of questions represented in Miro Board for Section 2, Questions 1-25

Code	SG Component	Item	Question Format
S2M1	BIPV/Roof PV/PVSD	Area Size	Area and/or size of BIPV/Roof PV/PVSD is important to the future smart grid connected homes.
S2M2		Inclination/Tilt	Inclination/tilt of BIPV/Roof PV/PVSD is important to the future smart grid connected homes.
S2M3		Orientation	Orientation of BIPV/Roof PV/PVSD is important to the future smart grid connected homes.
S2M4	Integrated shading device (ISD)	Placement (Location)	Placement of Integrated Shading Device is important for the future smart grid connected homes.
S2M5		Apply to all opening	ISD in all opening is important for the future smart grid connected homes.
S2M6		Area size	Area size of ISD is important for the future smart grid connected homes.
S2M7	Vertical Axis Wind Turbine (VAWT)	Location (Omni Direction)	VAWT's location is important for the future smart grid connected homes to enable ominous direction of prevailing wind.
S2M8	Battery (Energy Storage)	Placement	Placement of battery in the future smart grid connected homes is important.
S2M9		Ventilated space	Ventilation for the battery in the future smart grid connected homes is important.
S2M10		Heat dissipation	Heat dissipation for the battery in the future smart grid connected homes is important.
S2M11		Fire hazard	Fire hazard consideration for the battery in the future smart grid connected homes is important.
S2M12	Rapid EV Charging	Placement (Location)	Placement of Rapid EV Charging in the future smart grid connected homes is important.
S2M13		Pre-prepared infra	Preparing the infrastructure for the rapid EV charging in the future smart grid connected homes is important.
S2M14	Smart Meter / Sub-Metering	Placement	Placement of Smart Meter / Sub-Metering in the future smart grid connected homes is important.

S2M15		Selection of wall material	Selecting the type of wall material surrounding the smart meter/sub meter is critical in the future smart grid connected homes.
S2M16	IoT Connectivity	Wired	Wired connectivity for the IoT components is critical in the future smart grid connected homes.
S2M17		Wireless	Wireless connectivity for the IoT components is critical in the future smart grid connected homes.
S2M18		Wired and Wireless (Both)	Both wired and wireless connectivity for the IoT components is critical in the future smart grid connected homes.
S2M19	User-side sensors	Sensor Embedment	Embedding sensor into design aspect is critical in the future smart grid connected homes.
S2M20		Automated Shading	Automated shading devices are important in the future smart grid connected homes.
S2M21		All opening must be automated	Full automation for opening is critical for future smart grid connected homes.
S2M22	Integrated active opening	Automated Opening	All opening should be integrated with automation in the future smart grid connected homes.
S2M23	Electrical Fitting	Placement (Location)	Proper placement or location of electrical fitting is important in the future smart grid connected homes.
S2M24		Zoning	Zoning is important in the future smart grid connected homes.
S2M25		Aesthetically Sophisticated Interior Fittings	Aesthetically Sophisticated Interior Fittings is important in the future smart grid connected homes.

3. Data Analysis: Triangular Fuzzy Number and Defuzzification

According to Yusoff et. al (2021) the opinions of the experts were meticulously analysed using Microsoft Excel based program created by Jamil & Mat Noh (2021) known as FDMv2.0. The data analysis was conducted systematically, which is conducted two important concepts in FDM; Triangular Fuzzy Number (TFN) and the Defuzzification process. Triangular Fuzzy Number has two conditions, the first being that Threshold (*d*) must be less than 0.2. When the resulting value is less than or equal to 0.2, expert consensus has been achieved. The following formula is adopted to explain the calculation:

$$d(\widetilde{m},\widetilde{n}) = \sqrt{\frac{1}{3}[(m_1 - n_1)^2 + (m_2 - n_2)^2 + (m_3 - n_3)^2}$$

In FDM, the second condition for the Triangular Fuzzy Number is to involve a percentage of expert agreement. The traditional Delphi technique stated that if the expert group agreement exceeds 75%, it is accepted (Chu & Hwang, 2008; Murray & Hammons, 1995). Defuzzification Process, on the other hand, is the determination of the fuzzy (A) score value based on the α-cut value of 0.5 (Tang & Wu, 2010; Bodjonava, 2006). If the fuzzy score value (A) is equal to or greater than 0.5, then the measured item is accepted, and if less than 0.5, then the measured item is rejected. Defuzzification process (Amax) is a ranking process of each item to identify the importance level of each item. This ranking process was very helpful to determine whether to keep or discard certain items based on the following formula below. Thus, the determination of fuzzy (A) score value was made based on the following formula:

$$A_{max}=(\frac{1}{3}) \text{ x } (m_1 + m_2 + m_3)$$

Table 6 - Findings of expert consensus on dofsg items section 1 – smart grid components

Item / Elements	Condition of *Triangular Fuzzy Numbers (TFN)*		Condition of *defuzzification process*				Expert Consensus	Ranking
	Threshold value, d	Percentage of Experts Group Consensus, %	m1	m2	m3	Fuzzy Score *(A)*		
S1M1	**0.071**	**100.0%**	**0.827**	**0.964**	**1.000**	**0.930**	**ACCEPT**	2
S1M2	**0.175**	**100.0%**	**0.736**	**0.882**	**0.964**	**0.861**	**ACCEPT**	6
S1M3	*0.425*	*36.4%*	*0.345*	*0.482*	*0.627*	*0.485*	*DISCARD*	-
S1M4	*0.386*	*36.36%*	*0.600*	*0.745*	*0.836*	*0.727*	*DISCARD*	-
S1M5	**0.127**	**100.00%**	**0.791**	**0.927**	**0.982**	**0.900**	**ACCEPT**	5
S1M6	**0.081**	**90.91%**	**0.845**	**0.964**	**0.991**	**0.933**	**ACCEPT**	1
S1M7	**0.092**	**90.91%**	**0.827**	**0.955**	**0.991**	**0.924**	**ACCEPT**	3
S1M8	**0.099**	**90.91%**	**0.809**	**0.945**	**0.991**	**0.915**	**ACCEPT**	4
S1M9	*0.384*	*36.36%*	*0.518*	*0.673*	*0.800*	*0.664*	*DISCARD*	-
S1M10	*0.228*	*45.45%*	*0.573*	*0.745*	*0.882*	*0.733*	*DISCARD*	-

Condition:

Triangular Fuzzy Numbers
- Threshold value $(d) \leq 0.2$
- Percentage of expert consensus > 75%

Defuzzification process
- Fuzzy score (A) $\geq \alpha - cut\ value = 0.5$

Based on the findings in Table 6, only 6 items were below the threshold $(d) \leq 0.2$. Expert consensus showed that items above the threshold (d) did not fulfil the first condition of TFN. Items that met the threshold value (d) has a substantial expert agreement percentage of more than 90% for the 6 items in the Section 1 questionnaire. The result showed that only items listed in the Table 7 below were accepted by the expert panel input, including its rank of importance.

Table 7 - Items position by priority (Section 1)

Sort by priority	Code	Item	Question details
1	S1M6	Smart Meter / Sub-Metering	Smart Meter / Sub-Metering is an important component for a residential unit connected to the smart grid.
2	S1M1	BIPV/Roof PV/PVSD	Solar components (BIPV/Roof PV/PVSD) are important components for a residential unit connected to the smart grid.
3	S1M7	IoT Connectivity	IoT Connectivity is an important component for a residential unit connected to the smart grid.
4	S1M8	User-side sensors	User-side sensors is an important component for a residential unit connected to the smart grid.
5	S1M5	Rapid EV charging	Rapid EV charging is an important component for a residential unit connected to the smart grid.
6	S1M2	Integrated shading device	Integrated shading device is an important component for a residential unit connected to the smart grid.

Table 8 - Findings of expert consensus on DOfSG items section 2 – house design parameters

Item / Elemen	Condition of *Triangular Fuzzy Numbers (TFN)*		Condition of *defuzzification process*				Expert Consensus	Ranking
	Threshold value, d	Percentage of Experts Group Consensus, %	m1	m2	m3	Fuzzy Score *(A)*		
S2M1	**0.147**	**90.9%**	**0.718**	**0.882**	**0.964**	**0.855**	**ACCEPT**	3
S2M2	**0.202**	**81.8%**	**0.664**	**0.836**	**0.936**	**0.812**	**ACCEPT**	7
S2M3	**0.223**	**81.8%**	**0.718**	**0.864**	**0.936**	**0.839**	**ACCEPT**	5
S2M4	*0.358*	*27.27%*	*0.636*	*0.773*	*0.855*	*0.755*	*DISCARD*	-
S2M5	*0.334*	*54.55%*	*0.436*	*0.609*	*0.764*	*0.603*	*DISCARD*	-
S2M6	**0.181**	**90.91%**	**0.664**	**0.836**	**0.945**	**0.815**	**ACCEPT**	6
S2M7	*0.380*	*45.45%*	*0.327*	*0.473*	*0.627*	*0.476*	*DISCARD*	-
S2M8	**0.252**	**81.82%**	**0.682**	**0.827**	**0.918**	**0.809**	**ACCEPT**	8
S2M9	*0.299*	*63.64%*	*0.627*	*0.782*	*0.882*	*0.764*	*DISCARD*	-
S2M10	*0.289*	*27.27%*	*0.609*	*0.773*	*0.882*	*0.755*	*DISCARD*	-
S2M11	**0.194**	**81.82%**	**0.718**	**0.873**	**0.945**	**0.845**	**ACCEPT**	4
S2M12	*0.360*	*54.55%*	*0.527*	*0.673*	*0.791*	*0.664*	*DISCARD*	-
S2M13	*0.484*	*36.36%*	*0.455*	*0.582*	*0.700*	*0.579*	*DISCARD*	-
S2M14	*0.424*	*36.36%*	*0.627*	*0.745*	*0.818*	*0.730*	*DISCARD*	-
S2M15	*0.391*	*45.45%*	*0.445*	*0.600*	*0.736*	*0.594*	*DISCARD*	-
S2M16	*0.420*	*27.27%*	*0.355*	*0.536*	*0.709*	*0.533*	*DISCARD*	-
S2M17	*0.271*	*72.73%*	*0.645*	*0.800*	*0.900*	*0.782*	*DISCARD*	-
S2M18	**0.134**	**100.00%**	**0.718**	**0.882**	**0.973**	**0.858**	**ACCEPT**	2
S2M19	**0.154**	**90.91%**	**0.736**	**0.891**	**0.964**	**0.864**	**ACCEPT**	1
S2M20	*0.423*	*36.36%*	*0.464*	*0.618*	*0.745*	*0.609*	*DISCARD*	-
S2M21	*0.360*	*45.45%*	*0.373*	*0.536*	*0.691*	*0.533*	*DISCARD*	-
S2M22	*0.340*	*54.55%*	*0.582*	*0.736*	*0.845*	*0.721*	*DISCARD*	-
S2M23	*0.281*	*72.73%*	*0.664*	*0.809*	*0.900*	*0.791*	*DISCARD*	-
S2M24	*0.274*	*72.73%*	*0.682*	*0.827*	*0.909*	*0.806*	*DISCARD*	-
S2M25	**0.192**	**90.91%**	**0.627**	**0.800**	**0.927**	**0.785**	**ACCEPT**	9
S2M26	*#N/A*	*0.00%*	*#N/A*	*#N/A*	*#N/A*	*#N/A*	*DISCARD*	-
S2M27	*#N/A*	*0.00%*	*#N/A*	*#N/A*	*#N/A*	*#N/A*	*DISCARD*	-
S2M28	*#N/A*	*0.00%*	*#N/A*	*#N/A*	*#N/A*	*#N/A*	*DISCARD*	-
S2M29	*#N/A*	*0.00%*	*#N/A*	*#N/A*	*#N/A*	*#N/A*	*DISCARD*	-
S2M30	*#N/A*	*0.00%*	*#N/A*	*#N/A*	*#N/A*	*#N/A*	*DISCARD*	-

Condition:

Triangular Fuzzy Numbers

- Threshold value $(d) \leq 0.2$
- Percentage of expert consensus > 75%

Defuzzification process

- Fuzzy score (A) $\geq \alpha - cut\ value = 0.5$

Based on the findings in Table 8, only 9 items were below the threshold $(d) \leq 0.2$. Expert consensus showed that items above the threshold (d) did not fulfil the first condition of TFN. However, items that met the threshold value (d) has a substantial expert agreement percentage of more than 80% for the 9 items in the Section 2 questionnaire. The result showed that only items listed in the Table 9 below were accepted by the expert panel input, including its rank of importance.

Table 9 - Items position by priority (Section 2)

Sort by priority	Code	Item	Question Details
1	S2M19	Sensor Embedment	Embedding sensor into design aspect is critical in the future smart grid connected homes.
2	S2M18	Wired and Wireless (Both)	Both wired and wireless connectivity for the IoT components is critical in the future smart grid connected homes.
3	S2M1	Area Size	Area and/or size of BIPV/Roof PV/PVSD is important to the future smart grid connected homes.
4	S2M11	Fire hazard	Fire hazard consideration for the battery in the future smart grid connected homes is important.
5	S2M3	Orientation	Orientation of BIPV/Roof PV/PVSD is important to the future smart grid connected homes.
6	S2M6	Area size	Area size of ISD is important for the future smart grid connected homes.
7	S2M2	Inclination/Tilt	Inclination/tilt of BIPV/Roof PV/PVSD is important to the future smart grid connected homes.
8	S2M8	Placement	Placement of battery in the future smart grid connected homes is important.
9	S2M25	Aesthetically Sophisticated Interior Fittings	Aesthetically Sophisticated Interior Fittings is important in the future smart grid connected homes.

4. Discussion

Findings from the Fuzzy Delphi Method (FDM) analysis expert respondents have identified items that have reached expert consensus. There were several items that has been discarded as those elements did not achieve expert consensus. Accepted items will be integrated into the development of DOfSG framework. Furthermore, defuzzification process produced items' prioritization for each of the accepted elements. Section 1 of the questionnaire set intends to validate items concerning smart grid component have deduced six (6) significant elements for inclusion in the DOfSG framework. These accepted items depict needs to integrate technological advances relevant to the SG system in Malaysia, namely in ranking order; (1) smart meter and sub metering, (2) building integrated photovoltaic (BIPV), roof photovoltaic, photovoltaic sun shading device (PVSD), (3) IoT connectivity, (4) user-side sensors, (5) rapid electric vehicle (EV) charging hub and (6) integrated shading device.

In Section 2, out of the 30 items earlier identified for the FDM process, only 9 items were accepted for inclusion in the DOfSG framework. Expert consensus were reached for items that is ranked by importance; (1) sensor embedment, (2) wire and wireless IoT connectivity, (3) area sizing for solar PV installations, (4) fire hazard concerns of energy storage placement, (5) orientation of homes for solar PV optimization, (6) area size for integrated shading device (ISD), (7) inclination or tilt of the BIPV/Roof PV/PVSD, (8) placement of battery (energy storage) in the layout of future homes and, (9) interior fittings should be aesthetically designed to accommodate these smart technologies.

Expert panels also provided some input for the items being investigated and their comments were accounted for in this research. In 10 below, a list of the input that needs to be given special attention in the development of the DOfSG framework. Suggestions and comments acquired from the expert panel are imperative for future research consideration. Utilising the proposed DOfSG framework in Fig.5, a modified DOfSG version is developed.

Table 10 - Expert panel input for DOfSG consideration

Panel	Comments
Expert respondent 1	• Smart meter should be placed at the gate entrance for easy maintenance by utility company. • Conduit or trunking of wiring is not a priority for designers, but aspect focus for technical personnel. • Batteries / energy storage facilities should be feasible at the community level. • Home automation as the whole package as viewed by architects.
Expert respondent 3	• Smart home gateway (energy hub) is an essential component for the SG system in homes. • Proposed wind power utilization in Malaysia is not viable due to its inconsistent speed and reliability issue. • Area sizing for photovoltaic panel is not an issue if the efficiency is high.

	• Rapid EV charger should be connected to the three-phase grid inbound. • Smart meter is essential but not sub metering. Sub metering is an advantage to the users. • HEMS should be integrated as a whole package.
Expert respondent 4	• Smart home gateway (energy hub) is an essential component for the SG system in homes. • Home gateway is essential for a smart grid connected homes.
Expert respondent 6	• Initial capital cost maybe high for equipping the smart grid connected homes. • Home automation sizing could be considered for cost optimization. • Battery installation in individual homes is perceived costly. • Wireless connection efficiency has improved, barrier of wall construction is no longer a big issue. • Occupancy sensors is important for automation and energy conservation strategies.
Expert respondent 7	• Capital investment and Return on Investment (ROI) time for upgrades may become a barrier for adoption. • Tariff is still relatively cheap, so society not willing to spend. • Local battery / energy storage installation at the individual level may face maintenance and safety issue. If installed, it should be installed outdoor and is only for own use. • Battery is still costly to be integrated in homes at the individual level. • EV charging hub should be designed for super-charger use. • Sub meter should be able to be connected to the TNB grid infrastructure and system. • Not all sensors type should be integrated into this smart grid connected homes. Selective sensors for homes could be viable for cost optimization.
Expert respondent 8	• RE electricity generation should be widespread and connected at the community level (for solar panel and community level waste management -biomass electricity source). • Smart metering and sub meter should come as a whole package and provides services based on price signal from the real-time energy market. • Propose window integrated PV. • Battery is still considered expensive in the Malaysian market. However proper sizing of energy storage based on requirement of the user may be cost effective. • For EV charging, infrastructure of charging hub is considered expensive, and this service has yet to be widespread in Malaysia. Home installation for EV charging hub is anticipated. • Wind sourced electricity may be considered if use proper equipment and identify angle of attack for wind.
Expert respondent 10	• Wind not feasible for home installation in Malaysia. • Any form of technological equipment in the smart grid connected homes should be easily accessible for maintenance purposes. • Smart home package can be used to equip homes connected to the smart grid.
Expert respondent 11	• Solar tint film is suggested for integrated shading device (ISD). • As Malaysia is moving towards a low-carbon energy system that requires low-cost energy storage. Battery cost (energy storage) have fall significantly (https://ourworldindata.org/battery-price-decline), • Wind power could be considered but installation should be properly designed. • Rapid EV charging should use level 2 charging station and installed at the community level. • Zoning by area is good for energy conservation strategy.

Based on FDM approach via Triangular Fuzzy Number (TFN) and Defuzzification process, the former DOfSG framework was improved and redeveloped as shown in the Fig. below. The DOfSG framework denotes items investigated earlier in Fig. 5, rearranged to fit expert panels' consensus as well as accounting for the comments and recommendations highlighted by expert panel in Table 10.

Accepted items were re-categorized under main categories of Significant SG components, SG optimising strategies and house design components. The energy hub or HEMS have become a critical component connecting all items and as suggested by some panel expert, it should be developed as a whole package system for a smart grid connected homes. Unlike smart home components, a smart grid connected home only require certain smart technologies to be integrated in the building. Items under "SG optimizing strategies" and "House design components" were arranged according to its "ranked importance" by the expert panels.

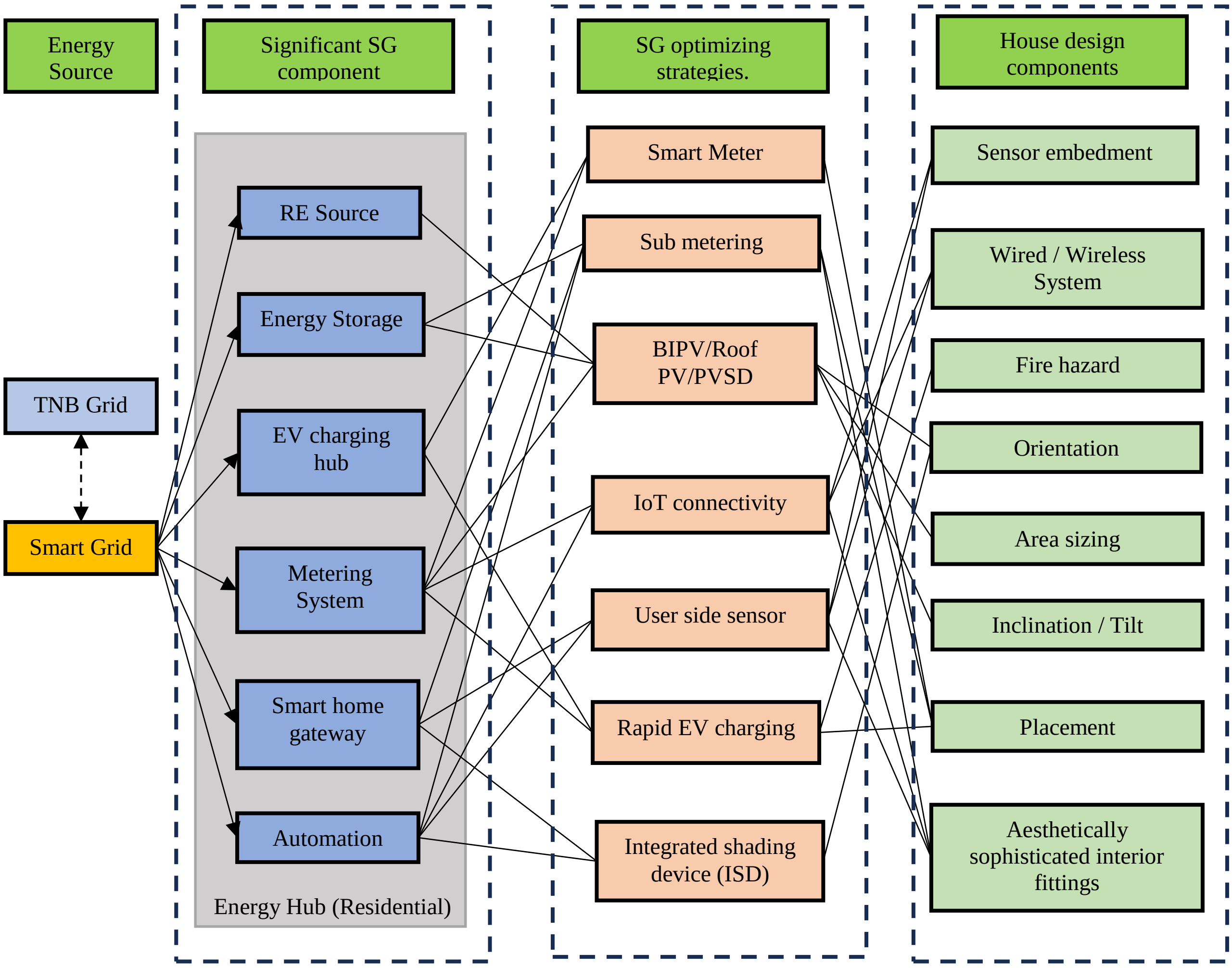

Fig. 9 - Proposed finalised Design Optimization for Smart Grid framework

5. Conclusion

In conclusion, energy optimization in residential building is crucial following its numerous benefits to the homeowners and the society. By prioritising energy optimization, the electricity dependent society can mitigate issues pertaining the detrimental impact of rising energy demand among the modern society. As the residential sector makes up the substantial portion of the overall national energy demand, improving energy efficiency in this sector may be beneficial. Energy optimization in homes may create a positive chain-reaction such as long-term cost saving, increased property value and decreased reliance on grid electricity therefore enhancing energy security. The advent of smart grid system in Malaysia marks an important development in the local energy sector, while this may enable the residential sector to benefit from these advances. As such, the development of the local residential sector may be aligned to suit the Smart Grid system, therefore benefitting from it. Residential design optimization for the smart grid system shall be more attractive to the larger society, as knowledge of integrating the relevant smart technologies and design adjustment becomes available. Thus, this study strives to develop a DOfSG framework that specifies the suitable smart technologies and design guide to enhance a residential unit towards the Malaysian smart grid system. The comprehensive DOfSG framework were developed based on expert panel consensus using Fuzzy Delphi Method to reveal critical items for the DOfSG. It was conducted in two steps; pilot survey and the FDM rounds on eleven (11) selected panel that represented both end of the research paradigm (smart grid and house design). The final items accepted in section 1 and section 2 of the questionnaire set (redesigned in graphical representation) were utilised in the DOfSG framework. Comments and suggestions from the expert panels were also considered in the framework. At a glance, the DOfSG framework highlights important element for future homes in the smart grid system including widespread RE integration, installation of battery energy storages, increased use of EV among homeowners therefore EV charging hub will become imperative, two-tier metering systems (utility smart meter and user sub-metering), proliferating sensor embedment in the residential unit, connectivity becomes mandatory for data exchange in the smart meter and HEMS and automation will also become necessary for optimizing energy demand and cost (energy price linked) following the incentive and penalty based demand response program. In the end, this paper intends to make significant contribution in the residential sector and the smart grid system, thus paving the way for a more sustainable future.

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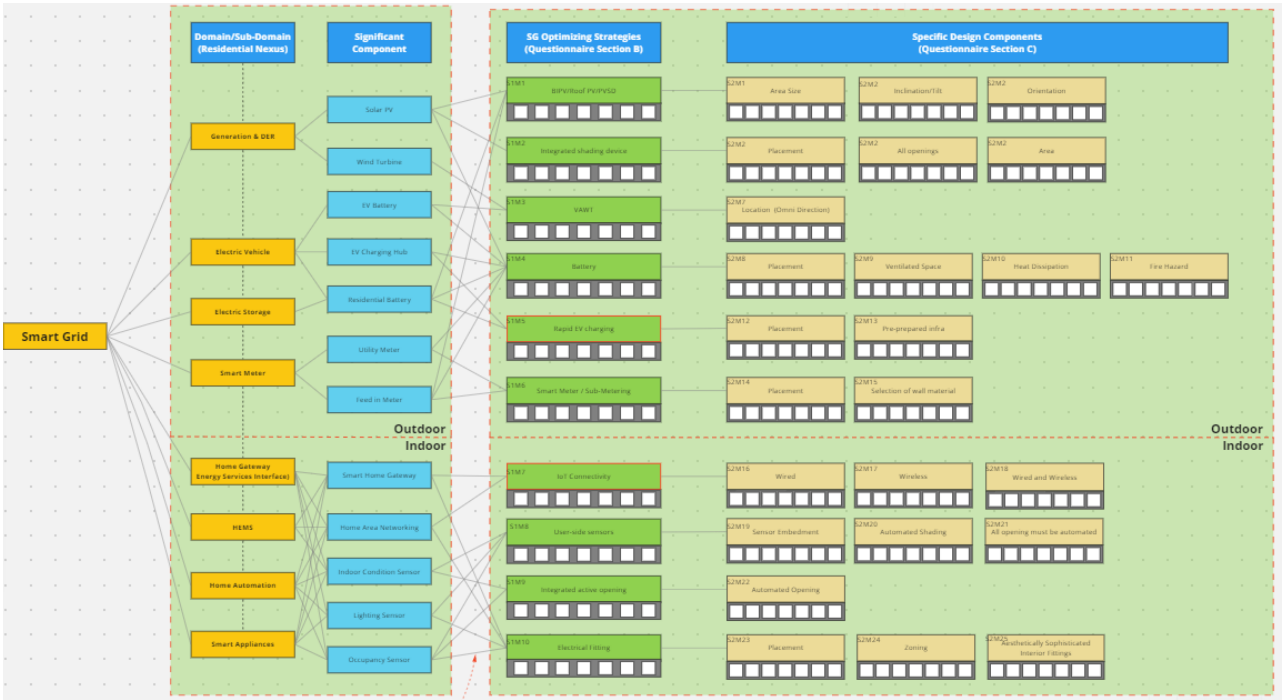
Appendix A: Example of Graphical Representation of Questionnaire Using Miro Board



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