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E-PROCEEDING OF

1st INTERNATIONAL E-CONFERENCE ON GREEN & SAFE CITIES 2022

"Sustaining the
Resilient, Beautiful and Safe Cities
for a Better Quality of Life"

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“Sustaining the Resilient, Beautiful and Safe Cities for a Better Quality of Life”

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ENERGY OPTIMISED DESIGN ATTRIBUTES CHECKLIST OF A TERRACE HOUSE NEXUS TO THE MALAYSIAN SMART GRID SYSTEM VIA CONTENT ANALYSIS APPROACH

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Abstract

Design plays a pivotal role in energy use for a residential unit. Alongside the nationwide smart grid system deployment, further energy optimisation strategies are possible through design enhancement of these residential units. Despite various advantages of the Smart Grid, design aspects connected to the Smart Grid system has yet to be explored. Thus, the aim of this paper is to identify the key attributes of smart grid system and design nexus intended to elucidate opportunities for further enhancements. A Smart Grid – Design Parameter (SG-DP) building checklist is developed and proposed based on content analysis approach conducted on thirteen (13) selected sustainable tools documents in Malaysia. Outcome of the building checklist proposed may provide critical insights regarding design attributes significant to the smart grid system and benefit the residential stakeholder.

***Keywords**: Smart Meter, Smart Grid System, Smart Grid Optimized Building (SGOB), Checklist, Terrace House*

INTRODUCTION

Malaysian smart grid (SG) deployment is timely as it solves the ills associated with the traditional grid. Widely adopted among developed countries, SG overcomes issues of electricity demand surge, detrimental impact of fossil fuel sources (in the electricity generation process), rise of renewable energy integration into the grid system and maintain the existing expensive asset (Liu et al., 2019; Sato et al., 2015; Yassein et al., 2018). This proven solution is replicated in the local electricity supply industry as Malaysia moves away from fossil fuel sources in various areas to meet 31% renewable energy (RE) ratio by 2025 and support government's initiatives.

The commencement of Malaysian smart grid (SG) transformation programme follows the conclusion of Melaka and Putrajaya smart meter pilot project (Syafiq et al., 2019). Nationwide smart meter installation is underway and various electricity grid infrastructures are transformed to equip the modern smart grid system. Alongside the Malaysian SG development progress, houses' design optimization fit for the SG system holds potential for energy use optimization in the residential sector. The way forward is to investigate key design attributes significant to the SG system intended for further study and propose its findings for future housing stock improvement. Thus, this paper aims to identify critical design parameters concerning buildings, energy consumption and the relevant smart grid components.

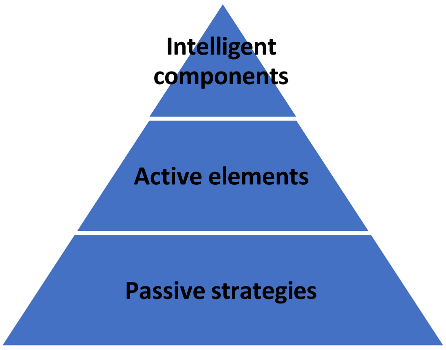
Design optimisation for energy conservation strategies

Buildings accounts for a third of the global energy demand, and its substantial portion is attributed to the residential buildings (Sadeghifam et al., 2019). Energy demand in residential buildings have been linked to changes in the modern lifestyle needs like air-conditioning use (Toe, 2013), increasing electrical and electronic device dependence (S. S. S. Ali et al., 2020, 2021) and, modern building design unsuited for the local climate (Mohammadi et al., 2009; Sadafi et al., 2012).

The research community have since engaged into improving energy use in buildings and revealed the tri-level approach; the long-standing and proven passive design strategies, the active design strategies fit for the modern lifestyle and recently, the intelligent embedded design strategies. The tri-level approach to energy efficient building is represented by conceptual diagram in Figure 1 below. The pyramid diagram denoted stages of implementation to reduce energy demand for buildings based on cost factor. In the modern society, energy becomes essential to support their daily routine resulting to energy intensive lifestyle. The rise in availability of electrical appliances and personal electronic devices also contributed to this modern lifestyle (Zakaria et al., 2021). Current pressing energy issue concerning modern dwellers is their relatively high energy consumption as energy intensive lifestyle becomes a norm leading to un-sustainable energy habits (Robiah Suratman et al., 2018; Siti et al., 2015). Based on this tri-level approach, increasing energy needs of the modern lifestyle could be fulfilled by the active elements in buildings to compensate for the shortfalls of the passive design approach. Cost has been widely discussed as the issue for implementation (El-Azab, 2021; Gamayunova et al., 2020; Rashid, 2018). Nevertheless, as energy intensive lifestyle becomes a norm, it is important to fulfil the demand for energy yet ensure conservation strategies are well in place.

Figure 1

Conceptual diagram of the tri-level approach to energy conservation strategies.



In addition, concerned stakeholders from the government and non-governmental bodies initiated several strategies to spread awareness and cultivate energy conserving lifestyle. "Green" proponents' agencies and government bodies alike have introduced various sustainable tools, design standards, design guidelines and by-laws that included energy efficiency and conservation strategies. These are (1) sustainable tools like Green Building Index (GBI) (2009), Malaysian Carbon Reduction & Environmental Sustainability Tool (MyCrest) (2015), Melaka Green Seal (2014), Green Real Estate (GreenRE) (2013), Low-Carbon Cities Framework (LCCF) (2019); (2) design standards and guideline such as Malaysian Standards (MS) i.e., MS 1525 and MS 2680; and (3) Uniform Building by Law

(UBBL). These tools, guidelines and by-laws are mostly focused on the passive design strategies, but some included the need to adopt active elements and smart technologies to achieve energy efficiency.

As the energy sector develops further with new technologies and innovation, similar developments are also expected in the residential sector as it copes with the advancement in technology. In the context of this paper, smart grid's progress may further enhance the design strategies in buildings, strengthening the tri-level approach as mentioned previously. Utilising technologies in relation to the smart grid system, design enhancement can be implemented in lighting, cooling, electrical appliances, and energy automation (Dileep, 2020).

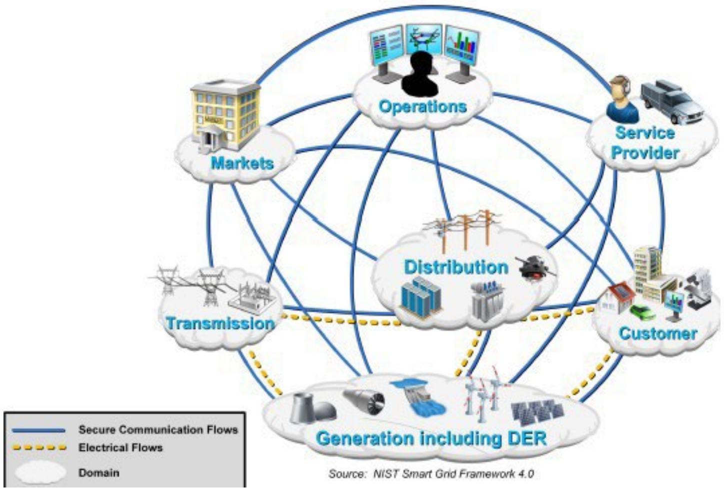
Potential smart grid components for design optimisation

Technology and innovation in the SG system is critical to replace the traditional model from generation to beyond the electricity meter. The convergence of these technologies is driving the SG transition: wide electrification, decentralisation and digitalisation (Dean et al., 2019; Martin et al., 2017). SG system enable transformation of the existing grid into an adaptive, self- healing, resilient, and sustainable bi-directional flow power system (Farhangi, 2010; Sato et al., 2015).

From the building sector perspective, SG transition necessitate future buildings to be fitted with innovative measures complementing energy efficiency and sustainable strategies brought about the SG system (Tiscareno & Villasenor, 2019; TNB, 2016). Within the SG ecosystem, SG components facilitates its operations as denoted by National Institute of Standards and Technology (NIST) and Institute of Electrical and Electronics Engineers (IEEE) via its SG conceptual model (Gopstein et al., 2021).

As shown in Figure 2Figure 2, the SG conceptual model consisted of seven major domains: operations, service provider, customer, generation (including DER-distributed energy resources), transmission, distribution and markets. Unlike the traditional grid, SG system operates with the support of digitalisation and a vast network of nodes enabled by the bi- directional data flow for real-time monitoring and control of the system (Shewale et al., 2020). Within these seven domains contains critical SG components that needs to be discovered for aligning design aspects therefore optimising the benefits of SG system for the building sector.

Figure 2.
NIST SG conceptual model (Gopstein et al., 2021).



Source: NIST Smart Grid Framework 4.0

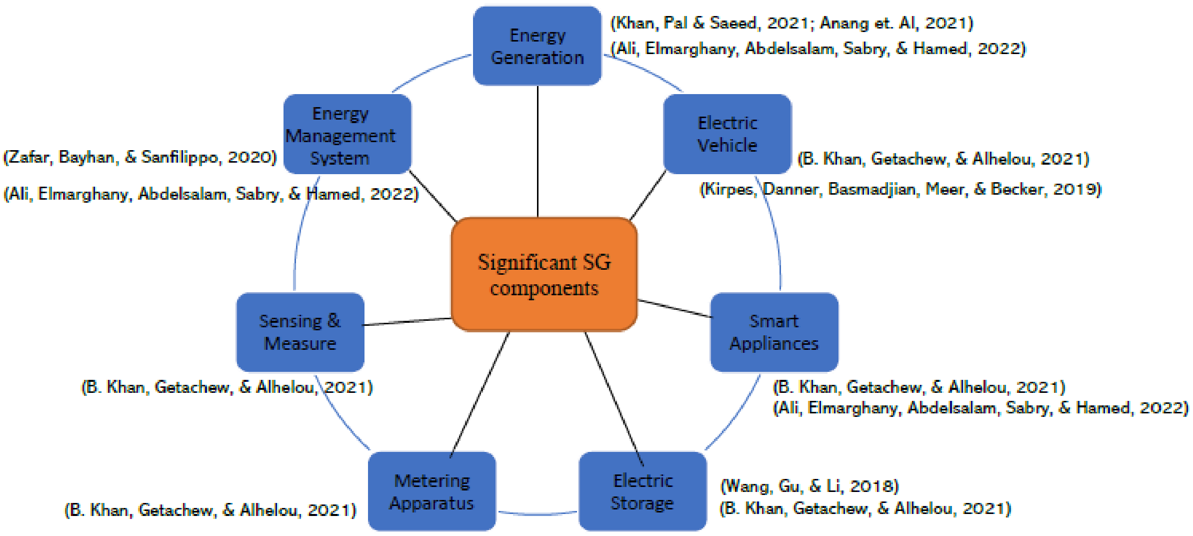
Smart grid component nexus to design optimisation strategies

The smart grid system indeed is an electrical power system dimension, but there are prospects for building design enhancements through the relevant smart grid components. According to the NIST Framework and Roadmap for SG interoperability 4.0 (Gopstein et al., 2021), an updated version of the previous SG conceptual model (2017), general characteristics of SG components are digital and advanced technologies adopted and integrated for monitoring, control and management of electricity supply, transmission and generation. In other words, these components are linked through digital communications incorporating intelligent equipment and appliances that hold key role in generation, transmission and distribution for the efficient utilisation of energy. Identification of SG components linked to buildings were initially carried out through literature searching, where seven components were identified. The seven components related to buildings are depicted in Figure 3 based on several literacy publications as shown below.

Specifically, the seven identified components operate in a predefined level, having different capabilities in understanding the flow of incoming power, optimal control and utilisation of existing services and infrastructure. The coordination, instigation and proper design of these SG components enable effective SG system operation together with the capabilities of involved stakeholders to reduce cost and environmental impacts (Farhangi, 2010; Nair & Zhang, 2009).

Figure 3

Significant SG component to the building sector.



In the energy generation component, building sector significant component is identified as renewable energy sources (RES). However, it has limited capacity and small scale in comparison to the overall SG system. Common RE in the building sector are solar and wind (S. S. Ali & Choi, 2020; Yilmaz et al., 2014). However, wind RE is not preferred as Malaysian wind has been known to be erratic and unsuitable for generating electricity. Despite hydro being plausible RE source, it is also not common for building use in Malaysia. Instead, it is adopted for large scale hydro-electric dam and managed by Independent Power Producer (IPP). Solar RE is therefore preferred, following its suitability for building use and installation (Ahmad & Byrd, 2013; Dimas et al., 2011). Furthermore, the decreasing cost and continuously improving conversion efficiency making it more attractive (Niranjan, 2020). Currently widely used solar RE are in the form of roof photovoltaic (PV) (F. A. Khan et al., 2021), Building Integrated Photovoltaic (BIPV) (Martin et al., 2017). and recently photovoltaic integrated shading device (PVSD) (Zhang et al., 2018). Statistical data show that Malaysian BIPV is on the rise (Zainuddin et al., 2021) and residential PV installations is considered as one of the promising options to generate and consume sustainable and cost-effective energy locally (Gercek & Reinders, 2019).

Secondly, electric vehicle (EV) is also identified as a significant building sector component that may affect design of a building. At the individual building level, EV integration requires proper allocation of the rapid charger, RE connected sources and electric storages (Biya & Sindhu, 2019; Lee & Choi, 2020).

Secondly, electric vehicle (EV) is also identified as a significant building sector component that may affect design of a building. At the individual building level, EV integration requires proper allocation of the rapid charger, RE connected sources and electric storages (Biya & Sindhu, 2019; Lee & Choi, 2020). At the larger collective buildings level, EV poses potential for community level charging stations that would benefit the local community in terms of energy use and monetization from the facility (Rashid, 2018). Correct design integration will allow optimization of EV use for the home occupants and increase value for the home unit. Driven by worldwide governmental policy support, UN's Sustainable Development Goals (SDG) and revolution in the energy and transportation sector around the world, EV market continues to increase in size. Thus, homes equipped with the EV facilities will make the unit more attractive for future homebuyers (Muzammil Idris, Fakrul Ramli, Aini Burok, Husnina Mohd Nabil, Ab Muis, Wai Shin, et al., 2019). So, alongside SG growth, EV market expansion shall facilitate the deployment of charging stations, rapid home charger and electricity storages (Biya & Sindhu, 2019). In addition, various concepts of EV are being proposed for the SG system like vehicle to grid (V2G) (Muzammil Idris, Fakrul Ramli, Aini Burok, Husnina Mohd Nabil, Ab Muis, & Wai Shin, 2019) and vehicle to home (V2H) (ben Slama, 2021). The electricity required for charging EVs will affect residential energy expenditures, making renewable energy sources more appealing as a means of offsetting grid electricity costs. Furthermore, localised generation and use reduces transmission loss and peak demand especially during EV charging process.

Third, intelligence, management and automation are another few buildings sector linked SG components. Referring to the tri-level building's energy efficiency approach (Figure 1) components of the SG system, SG focuses on the top two tier of the pyramid level i.e. active elements and intelligent components. In the context of this paper, there is a need for integrating the system into a building, requiring embedded infrastructure pre-planned and pre-designed like the electricity and lighting design. Early phase adoption enables optimization of energy consumption through strategies of active and intelligent approach. The automation in energy management system acts as a controlling mechanism to manage EV charging and avoid costly energy price based on the Time of Use (ToU) implemented by the utility company (Hussin et al., 2014). Smart appliances and building automation require certain degree of installation and varying levels of cost expenditure, therefore its instigation into the building shall require proper design decisions depending on the requirements of its occupants.

Fourth, energy storage shall be significant for buildings of the future. In the SG system environment, energy storage extends the functionality of the SG system that also benefit a single home unit (Hesse et al., 2017). Energy storage, such as batteries, guarantees the reliability of power within the SG system, as RE sources are intermittent. Customers can reduce expenditure on their electricity bills by using advanced energy storage facilities (Martin et al., 2017). A residential battery energy storage system package consisting of battery energy storage, roof-mounted solar PV and energy management system shall profit the homeowners in terms of economic optimization via well-matched design and adequate sizing (Hesse et al., 2017).

Fifth, informed consumers regarding their energy consumption pattern and the related cost expenditures may have a positive impact on their energy habits. Known as “feedback displays” are displayed data typically integrated into the energy management systems (EMS) that is linked to the smart meter. The smart meter is the node or gateway between the customer's premises and the utility, monitoring consumer's energy usage in real time (Lee & Choi, 2020). Thus, locating these display and sub-metering in the homes shall also be significant to the homeowners to glance through their daily consumption use and warn the energy users should their consumption be more than the suggested sustainable demand. Design decision to properly locate these devices shall have a positive impact on occupants’ energy consumption as they will be well informed (Sanguinetti et al., 2018). Also, this mechanism shall also allow consumers to participate in the energy market, unlocking the potential of building occupants by optimising energy demand and generation (Abdul-Razak, 2017).

Sensing and measurement play the role of the sixth SG component related to the building sector as shown in Figure 3. Sensors equipped in buildings enable energy management system (EMS) to effectively manage energy consumption, generation and storage for its local use. Artificial intelligence (AI) and machine learning (ML) technologies will enhance future EMS to accurate predict residential consumption and the amount to store. These advances typically require different forms of sensors and its related applications such as air temperature, humidity, air quality, light quality and motion. However, only certain sensors shall be relevant to the SG system and identified as those used for measuring appliance use, analysing consumption behaviour, monitoring, controlling and scheduling smart appliances (A. O. Ali et al., 2022). Integrated sensors through design shall ensure optimal function while maintaining its design aesthetics.

RESEARCH METHOD AND APPROACH

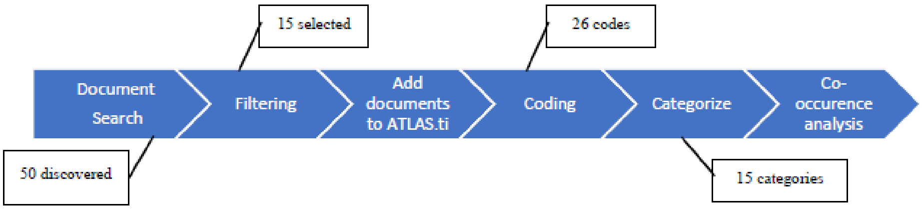
Content analysis method for building checklist development

Content analysis is a commonly used method for identifying, analysing and reporting patterns in the form of themes within a text (Snyder, 2019). This content analysis aims to identify Smart Grid components in the building sector linked to design attributes concerning energy use. A content analysis was performed on related documents concerning SG component nexus to building design parameters.

Software-supported content analysis can improve the systematicity of research while continuing to rely on and profit from the interpretive abilities of the researchers' (Schebesta, 2018). ATLAS.ti enables researchers to systematically uncover and analyse complex phenomena concealed in unstructured data (text, multimedia, images). Thus, ATLAS.ti 9 is utilised to compile and manage documents for the analysis systematically. A step-by-step process for ATLAS.ti in the content analysis was acquired from earlier published research (Pujara & P.Joshi, 2020). Their approach was modified to fulfil this study's aim, which involved six steps. The following figure denotes the sequence of the analysis.

Figure 4

Step to analysis in ATLAS.ti



Initiated by reviewing literacy publications discussing smart grid components and domains (Georgakarakos et al., 2018; B. Khan et al., 2021), a conceptual framework is created, as shown in Figure 3. Referred documents for the SG dimension are Smart Grid Standards (Sato et al., 2015) and the latest NIST Framework and Roadmap for Smart Grid Interoperability Standards (1108r4) (Gopstein et al., 2021). Both documents elucidate sufficient information to demarcate critical SG components related to the study and highlight keywords for identifying design attributes suited to the SG system. Based on the framework created the first step in the content analysis is performed. A document search was conducted to identify potential articles or publications for the content analysis. This phase discovered 50 official documents on standards and guidelines regarding energy and buildings. A subsequent filtering process was conducted to discard irrelevant publications resulting in 15 documents. These documents are acquired from Green Building Index (GBI), Malaysian Carbon Reduction & Environmental Sustainability Tool (MyCrest), Melaka Green Seal, GreenRE, Low-Carbon Cities Framework (LCCF), Malaysian Standard (MS) 1525, MS 2680, Uniform Building by Law (UBBL) and Building Energy Efficiency Technical Guideline for Passive and Active Design published by Building Sector Energy Efficiency Project (BSEEP). Later, all documents are added to ATLAS.ti 9. Coding process was performed on the selected documents utilising keywords discovered in the desktop research stage. Obtained keywords from smart grid components, smart grid domain and sub-domain is shown in Table 1. An analysis of co-occurrence was undertaken to determine the relationships between the codes.

Table 1

Keywords searching for coding in ATLAS.ti

Smart meter	Smart appliances	Energy storage
Solar Panel / PV /BIPV	Active control	Electricity layout
Electric Vehicle	EV charging	Orientation
Energy Management System (EMS	Active shading device (Internal and external)	Home automation
Home gateway	Sensor	Building form
Zoning / spatial organisation	Wind Energy	Smart switch
Opening design	Energy distribution	Active roof ventilation

Figure 5 represents a co-occurrence analysis between the codes developed based on the keywords, as shown in Table 1. Analysed occurrence link between codes is represented via a Sankey diagram, with items on the left signifying SG components and items on the right signifying design-related items that their respective categories have clustered. Arrow size in the Sankey diagram entails several occurrences between the selected and linked codes. The results of this analysis stage need an additional study on the SG components interconnecting the utility grid to the consumer premises.

Figure 6 describes vital components of the smart grid on the consumer side, an integrated system consisting of Smart Meter, Home Automation, Home Energy Management System (HEMS) and Home Gateway Energy Services Interface (ESI). A co-occurrence analysis was carried out to investigate linkages between the selected codes. It has been found that these crucial components could be integrated an Integrated Energy Management and Automation System (IEMAS). Like Figure 5, arrow size denotes SG components' importance to the sub- items of the IEMAS. The outcome of this analysis shall be utilised to select and categorise SG components in the building checklist development.

Figure 5

Identified SG components in Malaysian design reference document; Sustainable Tools, Malaysian Standards and BSEEP Guideline

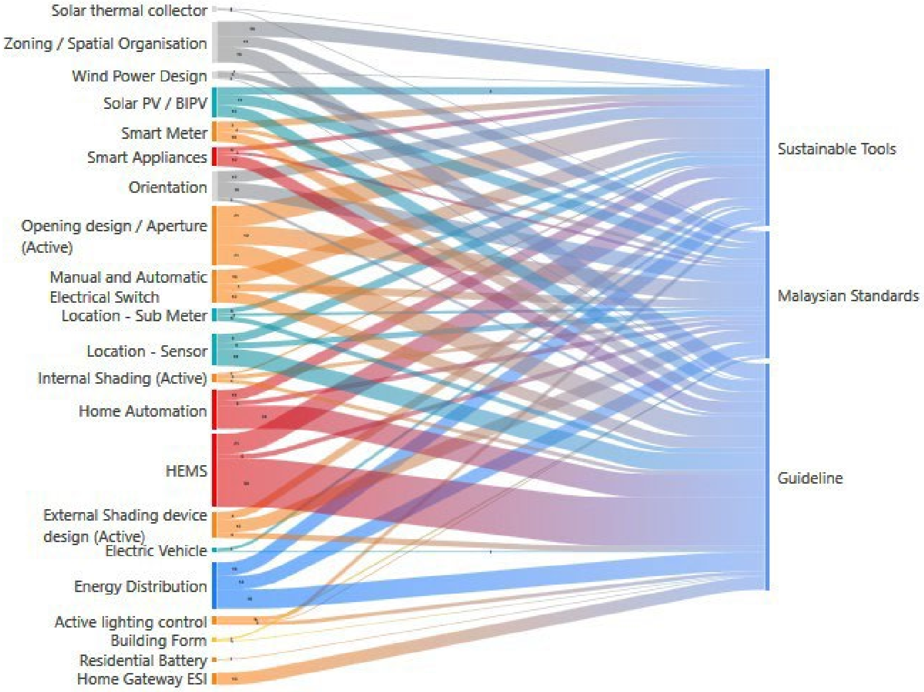
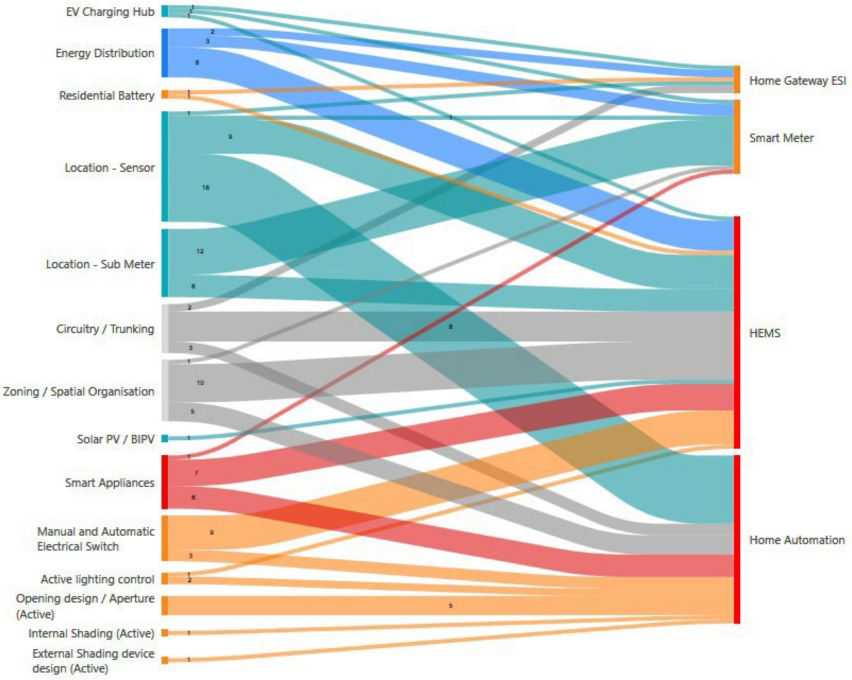


Figure 6

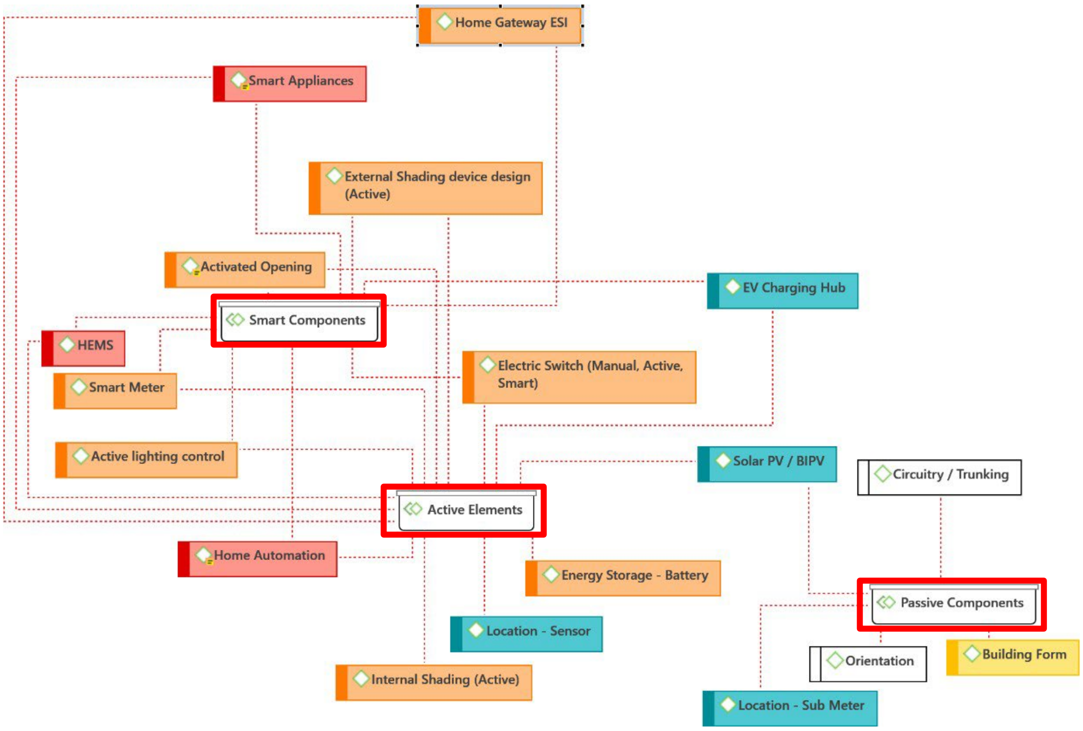
Co-occurrence Table – Integrated Home Energy Management System and Smart Meter to SG components.



The outcome of the earlier analysis enables the development of code categories as shown by Figure 7. A code-network representation of the categorising codes was created in ATLAS.ti 9 that visualises links between the codes based on the categories of passive components, active elements and smart components.

Figure 7

Code-Network for SG Components in relation to the building sector.



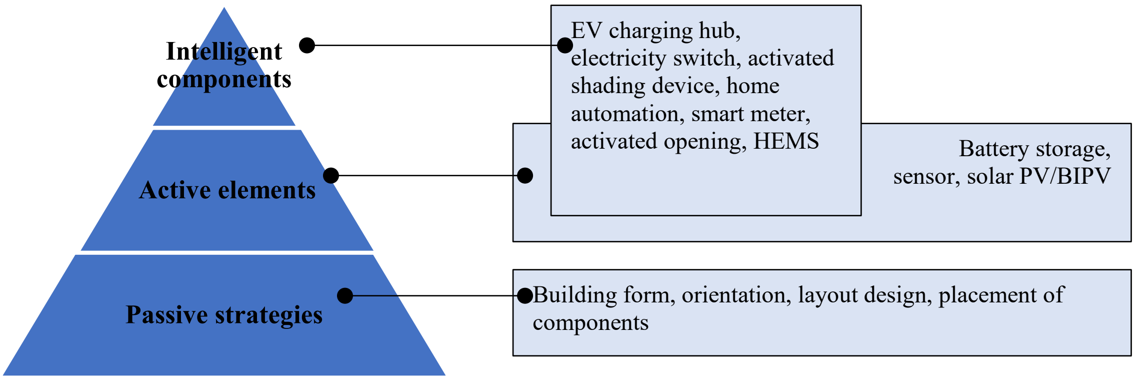
Represented as codes, related SG components were linked to the building sector for utilisation in this study. Thus, ATLAS.ti automatically generates the network diagram to graphically visualise connection between the identified codes. It also provided an overview of the identified codes from the content analysis, elucidating patterns and links that is vague in its former text structure. Additionally, it also creates are database of critical items across different documents used in this study.

FINDINGS AND DISCUSSION

Referring to the tri-level energy conservation diagram (Figure 1), this study revealed important relationship between the identified SG components to the items depicted in the conceptual diagram. Several codes were identified exclusively for one category (either passive, active or intelligent), but there are also codes that show relationship with two or more categories. The content analysis process uncovers only specific SG related components that is mapped against the energy conservation diagram as shown in the Figure 8 below.

Figure 8

The tri-level approach to energy conservation strategies mapped to SG significant components



The tri-level pyramid denotes stages of implementation of strategies to achieve energy conservation strategies for buildings. Items on the right represented content analysis output of the SG components significant to the building sector and its relationship to the stages of tri-level approach concept. Elucidated active elements and intelligent components through the process above are summarised in Table 2.

The content analysis approach for this study reveals relevant smart grid components for optimising the building's design parameters. Interestingly, components identified show similar traits of a smart home, that some researchers interchangeably use the term between a smart home and a smart grid connected homes (González et al., 2021; Homes et al., 2012; Leonardi et al., 2016; Zafar et al., 2020). Nevertheless, focus of this paper is the SG component of the SG to optimise homes for the SG system and uses the term SG Optimised Homes.

Discussion and summary of building checklist development

Optimisation strategies based on the content analysis depicts two strategies of design approach: passive and active. Furthermore, varying degrees of intelligence are also proposed for instigation depending on needs of the occupants and extent of willing to invest. The degree of smart technology adoption in the buildings concerns building owners as it translates into cost; capital expenditure (CAPEX), operational expenses (OPEX) and return on investment (ROI). Despite the similar characteristics of a "smart home", SG optimised homes only focuses on the aspects of components connected to the smart grid system and strategies taken to benefit from the grid. However, technological innovations only can be accepted only if the consumers see the benefits and feel able to take advantage of them (Wong-Parodi et al., 2016). Alternatively, cost effectiveness to install smart and active components may be achieved through basic economic indicators intended to achieve economic and energy efficiency (Gamayunova et al., 2020). In addition, the economic factors affecting capital expenditure on the technological advances can be divided into two categories; sizing cost for the installation and operating cost of the building (El-Azab, 2021).

Table 2
Smart grid components linked to building design

Design parameters (Passive)	Potential SG component	Smart	Active
Building form	Solar energy / solar PV / BIPV		
Orientation	Solar energy / solar PV		
EV charging infrastructure	Electricity layout, metering infrastructure, electricity storage	✓	✓
Smart meter and sub-meter location	Electricity layout, metering infrastructure, electricity storage	✓	
Zoning / Spatial organisation	Solar thermal, electricity layout		
Design parameters (Active)	**Smart grid components**		
Active lighting control	Energy Management System (EMS), electricity layout	✓	✓
Automatic, manual and smart electrical switch	Energy Management System (EMS), electricity layout	✓	✓
Smart shading device (external and internal)	Home automation, Energy Management System (EMS), electricity layout	✓	✓
Window (auto-opening and closing)	Home automation, Energy Management System (EMS), electricity layout	✓	✓
Openable roof design	Home automation	✓	✓

As part of the “smart home” concept, the Smart Grid optimised homes are equipped with automation that is not focused on occupants’ comfort, instead interacts with the SG system to provide and receive services (Darby, 2018). But energy consumption of the modern society is driven by changes in the lifestyle underpinned by the need to achieve comfort leading to the energy intensive lifestyle. Therefore, there is a need to balance between energy efficiency and needs of the modern society.

Hence, understanding the extent of smart technology adoption in the buildings enough to satisfy the optimisation strategies is essential. Table 2 demonstrates the findings above and categories of design parameter nexus to the SG components, presence of smart technologies and active characteristics.

In fulfilment of this study, the outcome of the content analysis is finalised with a building checklist development. This checklist contains significant smart grid components nexus to building design parameters, its location in the building and the presence of "smart technology" and "active component". Table 3 shows items utilised for the building checklist, acquired from selected smart grid references, Malaysian sustainable tools, Malaysian Standards (MS) guide, building by-Laws and voluntary guidelines.

Table 3
Building checklist: Smart Grid component residential nexus

Location			Evaluation			
Ex	**In**	**Smart grid components**	**Y**	**N**	**S**	**A**
		Smart meter				
		Sub metering				
		Electric Vehicle infrastructure				
		Sensors				
		Home automation system				
		Energy management system (EMS)				
		Home gateway Energy Services Interface (ESI)				
		Smart appliances				
		Solar PV				
		Building Integrated PV (BIPV)				
		PV Shading Device (PVSD)				
		Energy storage (battery)				
		Energy storage (other)				
		Smart switch / Smart Plug				
		Zoning / spatial arrangement				
		Climate control				
		Active shading device (internal)				
		Active shading device (external)				
		Automated window				
		Automated roof ventilation				

Ex- External; In-internal; Y-Yes; N-No; S-Smart component present; A-active component present

CONCLUSION

This paper describes a study effort in selecting components of the smart grid system and building design attribute suitable for optimisation strategies aligned with the smart grid system. The result of this study indicates that components of the smart grid linked to the residential unit are heavily dependable on the SG node; the smart meter, energy management system (EMS) and home automation. These components could be developed as a single entity known as Integrated Energy Management and Automation System (IEMAS). Additionally, SG components discovered depicts a certain degree of "smartness" and active characteristics. As such, the enhancement strategies imposed on residential buildings could be equipped with various active and intelligent technologies. Different amounts of these technologies would benefit different levels of social income group, thus benefiting the society's respective social class. Eventually, implementing these optimisation strategies would benefit a myriad of stakeholders across the residential sector. The study established a foundation for further research and analysis on design optimisation methodologies appropriate for the SG system, particularly in the Malaysian setting.

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