

## Development and Evaluation of a Modular KNX-Based Smart Building Automation Trainer Platform for Research and Education

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### Full Paper

#### Article history

Received

30 July 2026

Received in revised form

18 August 2026

Accepted

8 September 2026

Published online

1 November 2026



### Abstract

The rapid advancement of smart building technology has increased the demand for practical platforms that support education, research, and workforce development in building automation. However, many existing educational platforms are limited in functionality or not flexible enough for experimental research. Therefore, a modular KNX-based Smart Building Automation (SBA) Trainer Platform was proposed and developed for educational, research, and training applications. The proposed modular platform integrates essential KNX components, including a power supply, switching actuator, dimming actuator, shutter/blind actuator, fan coil actuator, Digital Addressable Lighting Interface (DALI) gateway, Windancer KNX, smart touch panel, and a portable modular hardware architecture configured with Engineering Tool Software (ETS). The trainer supports various practical applications including lighting and dimming control, shutter/blind control for up/down movement and positioning, fan coil speed control, smart weather sensor detection, real-time monitoring, and decentralized communication based on the KNX Protocol. In addition, the Smart Touch Panel provides connectivity with the GVS Smart ecosystem to combine a decentralized wired automation system (KNX) with app-based mobile control. This feature bridges local wall-mounted control and remote management. The experimental results demonstrate a 100% successful implementation of all control functions, reliable KNX bus communication without telegram loss and confirm stable real-time operation. A survey based on the Technology Acceptance Model (TAM) was administered to evaluate the efficacy of proposed platform for KNX education. Out the total population of 50 users, 48 respondents participated in the survey. Mean score analysis revealed high levels of Perceived Ease of Use ( $M = 4.7625$ ) and Perceived Usefulness ( $M = 4.8125$ ). The findings demonstrate that the proposed platform is highly acceptable to users, with respondents perceiving it as easy to use and useful for supporting KNX education. In conclusion, the proposed modular KNX-SBA trainer platform was successfully developed and evaluated. The trainer provides a cost-effective, scalable and portable environment for KNX educational and training while serving as a practical testbed for validating smart building automation algorithms and supporting research in smart buildings and the Internet of Things (IoT).

**Keywords:** - KNX, smart building automation, Engineering Tool Software (ETS), modular training platform, Internet of Things (IoT)

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## 1. Introduction

Industry 4.0 has accelerated the adoption intelligent buildings through the integration of merging physical spaces with digital ecosystems (Khan et al., 2024; Minoli et al., 2024; Kim et al., 2023). Consequently, Building Automation Systems (BAS) are increasingly prevalent in residential, commercial, industrial facilities and institutional buildings to manage function such as heating, ventilation, and air conditioning (HVAC), smart lighting, security, and energy management systems (Ahmad, 2025; Alongi, 2025; Netinant et al., 2024; Elkholy et al., 2022 & Elkholy et al., 2022).

Several communication protocols are used in BAS, including Konnex (KNX), Building Automation and Control Network (BACnet), Modicon Bus (Modbus), Zonal Intercommunication Global-standard (Zigbee), Z-Wave and others (Al-Fuqaha et al., 2024 & Toldo & Zanchetta, 2024). Among these, KNX is the most widely implemented international standards for building automation among various communication protocols. It provides interoperability among devices from different manufacturers, enabling the development of flexible, scalable and vendor-independent building automation systems (Vanus et al., 2023 & Rajendran, 2025). KNX technology has experienced rapid development due to increasing market demand (Garibmamadov, 2022 & KNX Association, 2025).

Consequently, many engineering institutions have incorporated KNX Courses in their curricula to provide students with practical exposure to KNX system installation, configuration, and commissioning using Engineering Tool Software (ETS). However, providing practical KNX training in educational institutions remains challenging because cost of industrial-grade equipment and infrastructure limitations. Virtual learning environments can provide opportunities for KNX programming and simulation but do not provide sufficient exposure to real physical wiring, hand-on troubleshooting, and tactile experience with industrial control panels. In contrast, conventional KNX trainer kits and demonstration panels generally provide hands-on hardware experience but offer limited functionality, lack usability, flexibility and research capabilities for advanced teaching and experimental research.

Therefore, this research develops a Modular KNX-Based Smart Building Automation (SBA) Trainer Platform that integrates real industrial-grade KNX devices with ETS6 in a modular and reconfigurable platform to address these limitations for educational, research, and training applications. The proposed KNX trainer combines hands-on hardware operation, ETS6-based configuration, modular system reconfiguration, and research-oriented experimentation within a single trainer. The trainer platform enables students or researchers to design, configure, commission and troubleshoot KNX-based automation application using actual KNX devices. It also provision of flexible and reconfigurable platform for different smart building automation experiment. These

features are intended to provide a more comprehensive learning and experimentation environment than conventional fixed demonstration panels or virtual-only KNX platforms.

The remainder of this paper are organised as follows. A literature review on comparison of existing KNX educational platforms are presented in Section 2. Section 3 describes the methodology for development the proposed trainer platform. The results and research finding are discussed in Section 4. Finally, Section 5 concludes the research conclusion and summarises the key contributions.

## 2. Literature Review

KNX Association has been set up in 1990 with headquarters in Brussels (Belgium), at that time still called “EIB Association” or in short “EIBA”. KNX also is recognized as an international standard (ISO/IEC 14543-3), allowing products from different manufacturers to communicate seamlessly using a common communication protocol and a unified configuration tool, the Engineering Tool Software (ETS) (Graveto et al., 2023; Ożadowicz, 2024 & Hamady, 2026). Unlike many proprietary systems, users are not restricted to a single vendor, providing greater flexibility for system expansion and maintenance. The advantages of KNX are vendor independence, long-term investment protection, wide availability of compatible devices, interoperability, scalability and high reliability compared with conventional electrical installations and proprietary automatic systems (Domingues et al., 2016 & KNX Association, 2025). Furthermore, KNX supports remote monitoring and easy integration of multiple building services, making it a suitable platform for smart building applications in education, research, and industry.

A comparison of existing KNX educational platforms reported in previous studies is presented in Table 1. Several KNX educational platforms have been reported, but most are designed primarily for basic teaching purposes and offer limited flexibility for advanced research activities. Most of these systems are fixed in configuration, less portable, or highly dependent on the simulation environment. In 2019, a KNX-based home automation simulator for smart home system education was proposed by Tasyon and Cetin. This simulator provides a modular KNX platform integrated with ETS software. However, it offers limited hands-on experience with real industrial KNX hardware. In 2023, Jafaar et al. introduced the KNX Trainer Kit as a teaching and learning tool for students enrolled in a Building Automation Systems (BAS) course. However, this trainer focuses more on classroom teaching rather than supporting flexible research applications. In addition, Majcher and Boguta proposed a KNX virtual learning platform that allows students to learn KNX programming without using physical KNX devices. However, this platform does not provide practical experience in wiring, commissioning, or troubleshooting real KNX hardware.

Based on this comparison, the main gap identified in the existing literature is not the absence of KNX educational tools, but the lack of a single platform that combines real

KNX hardware, ETS-based configuration, modular reconfiguration, usability and support for experimental research. Therefore, the proposed Modular KNX-Based Smart Building Automation Trainer platform is designed to address this gap by integrating industrial-grade KNX hardware, ETS6 software, modular architecture, usability and research capabilities into a single educational platform

suitable for teaching, training and experimental research. The proposed trainer platform offers a flexible, portable and industry-oriented learning environment, allowing students and researchers to gain hands-on experience in the design, configuration, commissioning and troubleshooting of real KNX systems.

Table 1: Comparison of existing KNX educational platforms

| Study                            | Platform Type                                  | Real KNX Hardware | ETS Integration | Modular Design | Portable | Research capability | Scalability |
|----------------------------------|------------------------------------------------|-------------------|-----------------|----------------|----------|---------------------|-------------|
| Toyfan & Cetin (2019)            | KNX-based home automation simulator            | Limited           | ✓               | ✓              | ✓        | Limited             | Limited     |
| Garibmamadov (2022)              | KNX educational/training platform              | ✓                 | ✓               | Limited        | Limited  | Limited             | ✓           |
| Jafaar et al. (2023)             | KNX Trainer Kit for Building Automation course | ✓                 | ✓               | Limited        | ✓        | Limited             | Limited     |
| Majcher & Boguta (2024)          | KNX Virtual learning platform                  | ✗                 | ✓               | ✓              | ✓        | Limited             | ✓           |
| KNX NextGen Programme (2025)     | KNX education training programme/platform      | Limited           | ✓               | Limited        | ✓        | Limited             | ✓           |
| <b>Proposed Trainer Platform</b> | Modular KNX-Based SBA Trainer                  | ✓                 | ✓ (ETS6)        | ✓              | ✓        | ✓                   | ✓           |

### 3. Methodology

#### 3.1 Research Framework

In this study, the system development lifecycle consists of five structured engineering phases are used for development of the Modular KNX-Based Smart Building Automation Trainer Platform as shown in Fig.1.

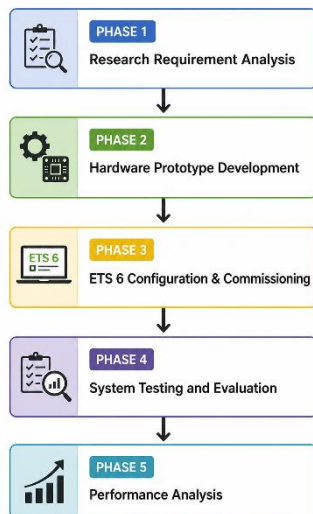


Fig. 1: Research methodology framework

Phase 1 is research requirement analysis, where the project requirements and system specifications are identified. Then, these requirements guide the physical assembly and integration of hardware components in Phase 2. The hardware platform is then configured and commissioned in Phase 3 during which KNX devices are programmed, communication networks are established,

and system functions are integrated. Then, the platform undergoes

Phase 4 is system testing and evaluation. The platform will undergo comprehensive system testing and validation across 20 iterations of each functional module. In addition, test procedures assessing bus response time (ms), telegram delivery success rate (%), and signal integrity/voltage drop will also be tested for functionality. The success criteria are to ensure zero missed KNX telegrams with a delivery rate of 100%, as well as an end-to-end response latency of below 100ms under normal operating load. Operational issues and configuration errors are identified and resolved during this phase using ETS diagnostics and oscilloscope signal analysis.

Finally, Phase 5 evaluated the operational efficiency and educational effectiveness of the platform through a combination of functional testing and user feedback. To assess educational utility, a 5-point Likert scale questionnaire was administered to a cohort of 48 users. A questionnaire based on the Technology Acceptance Model (TAM) model was used to evaluate the proposed KNX trainer platform among educators attending KNX courses. Survey responses and performance data were analyzed using descriptive statistics to demonstrate the practical and instructional advantages of the platform over conventional trainers.

#### 3.2 KNX-Based Smart Building Automation Design Layout

Fig. 2 shows the design layout of the proposed KNX-Based Smart Building Automation System. The design layout consists of several KNX components, including a KNX Distribution Board (DB) in bedroom, shutter/blind controller and smart touch panel in living room, HVAC controller and Digital Addressable Lighting Interface

(DALI) lighting in kitchen, and Windancer weather station at outside building. These components are integrated to provide a comprehensive smart building automation platform for system control, monitoring, and evaluation.

### 3.3 Hardware Prototype Development

Fig. 3 shows the block diagram of the proposed trainer platform. The proposed trainer platform integrates essential KNX components and a portable modular hardware architecture configured with Engineering Tool Software (ETS). The trainer supports various practical applications including lighting and dimming control, shutter/blind control for up/down movement and positioning, fan coil speed control, smart weather sensor detection, real-time monitoring, and decentralized communication based on the KNX Protocol

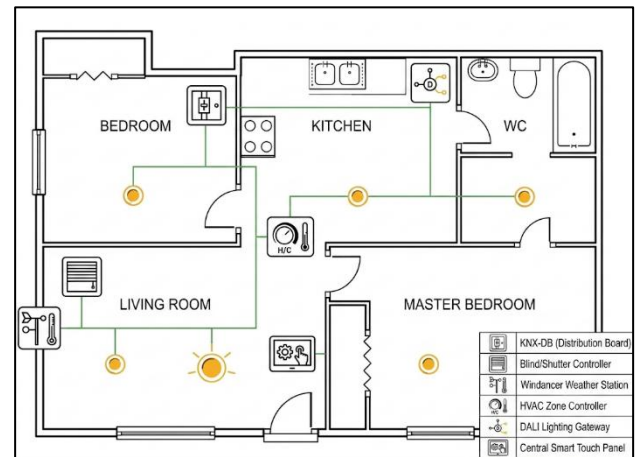


Fig. 2: KNX-based smart building automation design layout

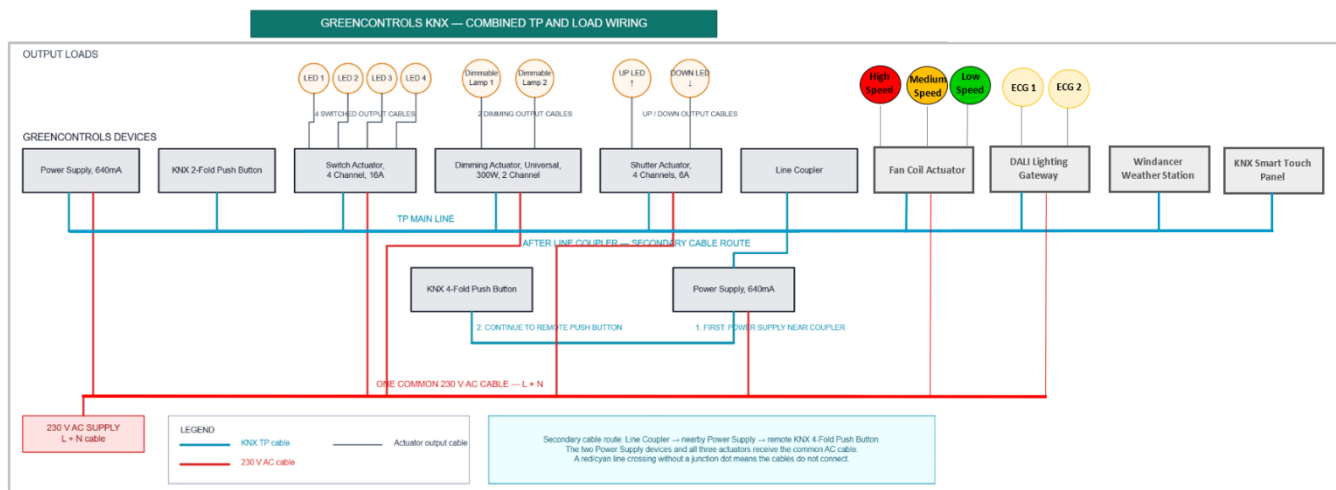


Fig. 3: Block diagram of the proposed trainer platform

#### a) Switching actuator

The KNX Switch Actuator with secure is a device used in building automation systems to switch electrical AC loads, such as lighting, heating systems, and signaling devices. The device features four independent outputs, each with a maximum switching capacity of 16 A (AC1) or 20 A (C-load), manual switch operation, and visible switching status indicators as shown in Fig. 4.



Fig. 4: Switching actuator, 4 channel, 16A/20A KNX secure

#### b) Dimming actuator

This Dimming Actuator is a Trailing Edge Dimmer designed for installation in distribution board and suitable for control for high powered dimming of different loads type (incandescent lamps, 230 VAC halogen lamps or low voltage halogen lamps on electronic or conventional transformers). Each dimmer actuator is parameterized via ETS with connection to KNX.

#### c) Shutter/blind actuator

The KNX shutter/blind actuator is a DIN-rail mounted device designed to independently control motorized shading products, such as roller shutters, blinds, awnings, and ventilation flaps. It provides precise automation, slat positioning, and motor safety features for commercial and residential buildings.

#### d) Digital Addressable Lighting Interface (DALI) gateway

DALI Lighting Gateway bridges the KNX bus network with the specialized DALI fixtures. It handles smooth dimming commands, scene control, and individual address

management for the orange light icons spread across the rooms

#### e) Windancer KNX

The KNX weather station with GPS receiver and shading control is used to measure temperature, wind speed, brightness, and precipitation, while also providing logic gate functions as illustrated in Fig. 5. All measured values can be used to control limit-dependent switching outputs. The operating states can be linked using AND and OR logic gates to enable flexible automation control. In addition, the weather station receives GPS signals to determine the time and location, allowing it to calculate the exact position of the sun (azimuth and elevation). The integrated shading control enables intelligent sun protection for up to eight building façades.



Fig. 5: Windancer 2.0 GPS KNX

#### f) KNX Smart Touch Panel

The KNX Smart Touch Panel as a capacitive room controller designed to manage smart building functions directly from a single localized interface. It acts as a centralized interface for smart building automation, functioning in this image as an HVAC controller for a fan coil unit. It provides a real-time display of the ambient room temperature (26.0 °C) alongside intuitive control elements to adjust target setpoints, choose operation modes, and turn the climate control system on or off.

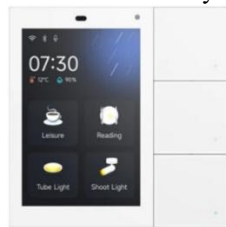


Fig. 6: KNX smart touch S3

### 3.4 ETS 6 Configuration and Commissioning

Based on Fig. 7, the ETS 6 configuration and commissioning workflow consists of four essential steps to integrate and set up devices within a KNX system:

#### Step 1: Device Import and Cataloging

The product databases (.knxprod) for each specific modular component are imported into the ETS 6 project data repository. As shown in Fig. 8, Import the in KNX-DALI Gateway from Catalog to KNX-DB box.

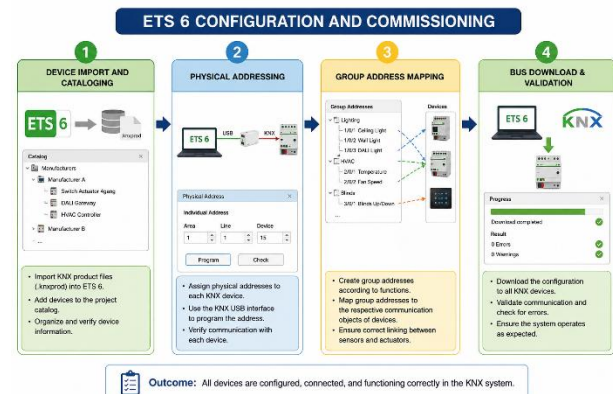


Fig. 7: ETS 6 Configuration and commissioning

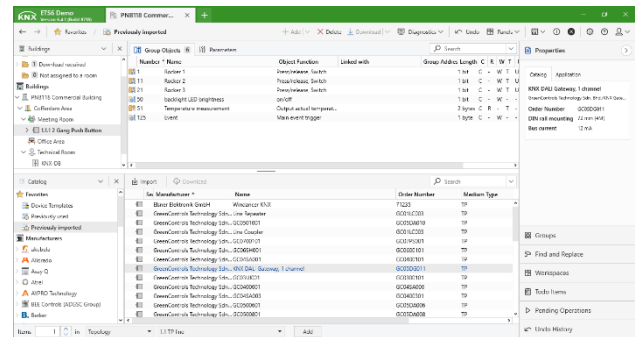


Fig. 8: Import the in KNX-DALI gateway from catalog to KNX-DB box

#### Step 2: Physical Addressing

An unique physical addresses (e.g., Area.Line.Device) are assigned to each coupler, actuator, and sensor node to establish their distinct identities on the twisted-pair (TP) bus as presented in Fig. 9.

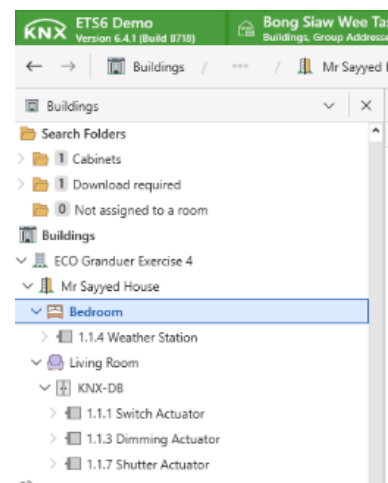


Fig. 9: Physical addressing

#### Step 3: Group Address Mapping

A multi-level group address structure (Main/Middle/Sub) is established to logically link group objects (inputs from sensors/touch panels to outputs on actuators), enabling decentralized peer-to-peer communication without a central controller as shown in Fig.10.

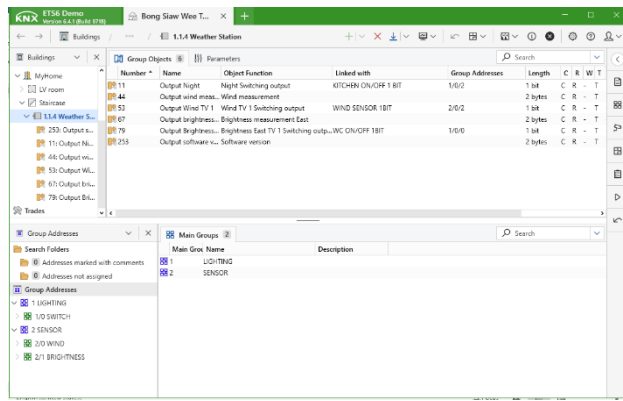


Fig. 10: Group address mapping

#### Step 4: Bus Download and Validation

The configured topology, parameter sets, and communication flags are downloaded to the physical modules via an IP or USB interface for runtime execution as illustrated in Fig.11.

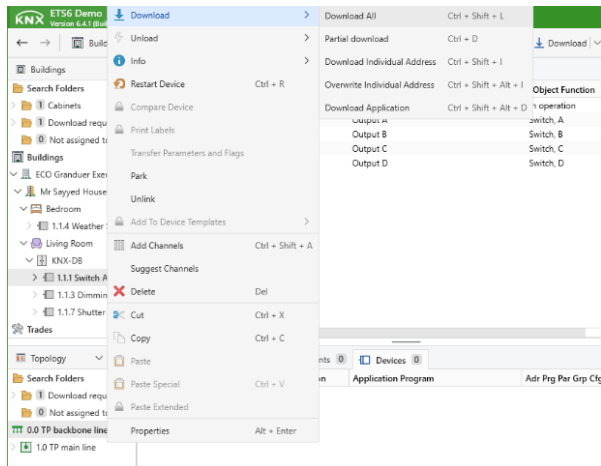
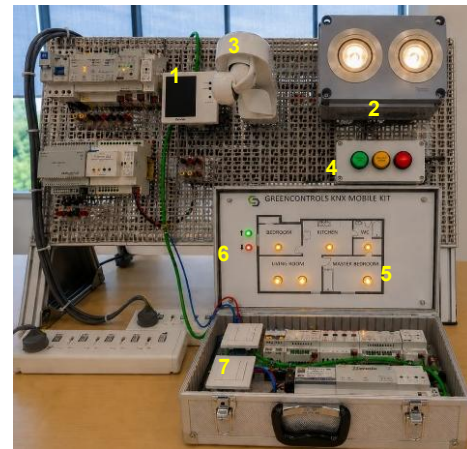


Fig. 11: Bus download &amp; validation

## 4. Result and Discussion

### 4.1 Implementation of the Developed Modular KNX Trainer Platform

Fig. 12 shows the developed modular KNX-based smart building automation trainer platform. The proposed platform successfully integrates industrial-grade KNX components into a compact and flexible training environment. The modular architecture allows individual KNX devices to be configured, tested, and modified according to different building automation scenarios as shown in Fig. 13 and Fig. 14.



#### Indicate

1. KNX Smart Touch Panel
2. Digital Addressable Lighting Interface (DALI)
3. Windancer KNX
4. Fan Coil
5. LED / Bulb
6. Shutter/blind
7. Push Buttons

Fig. 12: KNX-based smart building automation trainer platform



Fig. 13: Light dimming control and shutter position control



Fig. 14: HVAC control by using smart touch panel

Fig. 15 illustrates the GVS smart mobile application integrated with the KNX-based smart building automation platform. The application provides a graphical user interface (GUI) for real-time monitoring and control of KNX devices via a smartphone. Various building loads, including lighting and room appliances, are displayed together with their connection status, allowing users to perform remote switching and monitoring. The GVS Smart ecosystem bridges the decentralized KNX wired automation infrastructure with cloud-enabled mobile access, providing a user-friendly interface while maintaining the reliability, flexibility, and interoperability of the KNX standard.

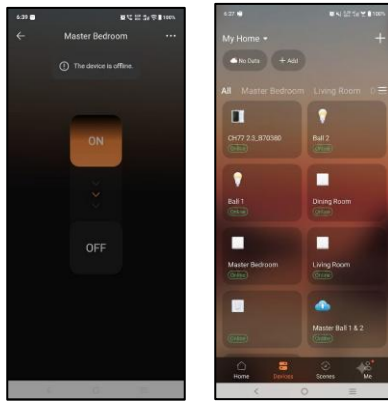


Fig. 15: GVS smart application

#### 4.2 Functional Performance Testing of KNX Automation Scenarios

Table 2 shows the functional testing results that indicate all configured KNX scenarios operated successfully. The communication between sensors, control devices, and actuators was achieved through KNX telegram exchange without communication failure. The developed trainer platform provides an effective hands-on learning environment for students or researchers to understand KNX system architecture, ETS6 programming, device commissioning, and troubleshooting processes.

Table 2: Functional testing results

| Test Scenario              | Input Device       | Output Device      | Result |
|----------------------------|--------------------|--------------------|--------|
| Manual lighting control    | Push button        | Switching actuator | Pass   |
| Automatic lighting control | Presence sensor    | Lamp               | Pass   |
| Blind control              | Push button        | Blind actuator     | Pass   |
| HVAC control               | Temperature sensor | HVAC controller    | Pass   |

#### 4.3 KNX Communication and Telegram Analysis

Table 3 shows the KNX Group Monitor was used to verify telegram transmission between KNX devices. The successful transmission of switching commands confirmed reliable communication through the KNX twisted pair bus.

Table 3: KNX Communication and telegram analysis

| Telegram    | Source      | Destination | Status   |
|-------------|-------------|-------------|----------|
| ON command  | Push button | Actuator    | Received |
| OFF command | Push button | Actuator    | Received |

The experimental evaluation confirms that the modular KNX trainer platform achieves industrial-grade reliability. These results show that the modular interface board and custom interconnect bus do not introduce signal degradation, impedance mismatch or packet collisions into the standard KNX bus infrastructure. This shows that the Trainer platform is a significant improvement over existing

systems by bridging the gap between pure software simulators, which lack physical problem solving, and rigid industrial benches that restrict active wiring design. Ultimately, these results show that the platform provides a flexible and cost-effective tool that accelerates students' mastery of KNX commissioning while offering researchers an open-access hardware testbed for IoT integration, energy optimization and smart building algorithm development.

#### 4.4 Comparison with Existing KNX Educational Platforms

Table 4 shows a comparison between the proposed KNX trainer platform and existing KNX education platforms. In 2019, Toyman and Çetin developed a KNX home automation simulator by providing an effective virtual learning environment but did not support direct configuration using real KNX hardware. Garibmamadov (2022) demonstrated the implementation of industrial KNX devices for practical learning. This platform mainly focused on system implementation rather than a modular and portable educational trainer. Jafaar et al. (2023) built a Fixed Panel KNX Trainer Kit but it was limited to fixed basic training, not offering the flexibility to modify the bus topology or reconfigure device groups. In contrast, the proposed trainer platform integrates real KNX hardware, ETS6 programming, modular architecture, usability and research capabilities into a single platform suitable for engineering education and future research activities.

Table 4: Comparison between proposed KNX trainer platform with the existing KNX educational platforms

| Author(s) / Platform             | Platform Type & Scope                        | Key Educational & Technical Limitations                                                                                                       | Advantages of the Proposed KNX Trainer Platform                                                                                                     |
|----------------------------------|----------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------|
| Toyman & Çetin (2019)            | Virtual KNX Home Automation Simulator        | Purely virtual simulation; lacks physical hardware interaction, and real-world wiring troubleshooting experience.                             | Integrates physical KNX hardware with ETS6 programming, bridging the gap between simulation theory and real-world hardware commissioning.           |
| Garibmamadov (2022)              | Industrial KNX Educational Benches           | Heavy, stationary bench setup; high cost per unit; focused strictly on standard installation routines without research expansion hooks.       | Offers a portable, cost-effective design equipped with external measurement points for both classroom instruction and advanced research activities. |
| Jafaar et al. (2023)             | Fixed-Panel KNX Trainer Kit                  | Rigid, pre-wired panel layout; limited to fixed basic exercises, offering no flexibility to modify bus topology or reconfigure device groups. | Features a modular, plug-and-play architecture, allowing dynamic reconfiguration of topology, actuators, and sensors for multi-level learning.      |
| <b>Proposed Trainer Platform</b> | Modular, Hardware-Based Portable KNX Trainer |                                                                                                                                               | Unified Ecosystem: Combines real hardware, ETS6 programming, high modularity, portable deployment, and research telemetry capabilities.             |

#### 4.5 Research Finding for the Effectiveness Study of using Proposed Trainer Platform for KNX Advance Course

The questionnaire items were adapted from previous research, namely the Technology Acceptance Model (TAM) (Davis, 1989) and subsequent TAM-based research in educational technology studies by Deris & Nazir, 2019. The study findings will be presented in a table containing the mean scores and percentages calculated. The results are then interpreted based on the level determination criteria presented in Table 5, which were adapted from the method proposed by Landell (1997). A questionnaire was employed as the research instrument, using a five-point Likert scale to evaluate the participants' perceptions of the proposed KNX trainer platform.

Table 5: Level determination table according to mean score

| Level Mean  | Score  |
|-------------|--------|
| 1.00 – 2.33 | Low    |
| 2.34 – 3.66 | Medium |
| 3.67 – 5.00 | High   |

Part I presents the demographic characteristics of the participants involved in the study. Parts II and III present the analysis of participants' perceptions regarding the effectiveness and acceptance of the proposed KNX trainer platform.

##### i. Part I: Participant Demographic Information

The demographic characteristics of the participants were obtained from Part I of the questionnaire, which collected information on gender, race, and prior experience with KNX and building automation systems as shown in Table 6. A total of 48 educators who attended the KNX course participated in this study.

Table 6: Frequency distribution and percentage of respondents

| Respondent Profile                             |              | Frequency | Percentage (%) |
|------------------------------------------------|--------------|-----------|----------------|
| Gender                                         | Male         | 31        | 64.58%         |
|                                                | Female       | 17        | 35.42%         |
| Race                                           | Malay        | 38        | 79.17%         |
|                                                | Chinese      | 4         | 8.33%          |
|                                                | Indian       | 0         | 0%             |
|                                                | Other        | 6         | 12.5%          |
| Prior Experience with KNX / Automation Systems | Beginner     | 0         | 0%             |
|                                                | Intermediate | 18        | 37.5%          |
|                                                | Advanced     | 30        | 62.5%          |
| Total Respondent                               |              | 48        | 100%           |

##### ii. Part II: Perceived Ease of Use (PEOU)

Perceived Ease of Use (PEOU) refers to “the degree to which a user believes that using a particular system or application will be free of effort” (Davis, 1989). Table 7

is presented the items on perceived ease of use refer to respondents' feedback on the acceptance of using the proposed KNX trainer platform in KNX course.

Table 7: Analysis of mean score and standard deviation for PEOU of the Proposed KNX trainer platform

| Code               | Statement Items                                                                     | Mean Score | Score |
|--------------------|-------------------------------------------------------------------------------------|------------|-------|
| PEOU1              | I find the KNX trainer platform easy to use.                                        | 4.7708     | High  |
| PEOU2              | It is easy for me to perform KNX configuration using the trainer platform.          | 4.5625     | High  |
| PEOU3              | I find it easy to use ETS6 with the KNX trainer platform.                           | 4.8125     | High  |
| PEOU4              | The functions and controls of the KNX trainer platform are easy to understand.      | 4.8542     | High  |
| PEOU5              | I can easily perform different KNX practical activities using the trainer platform. | 4.8125     | High  |
| Average Mean Score |                                                                                     | 4.7625     | High  |

Generally, based on the percentage of respondents' agreement for each item in the usability perception studied, it can be proven that the proposed KNX Trainer platform has been well received by the respondents. The average mean score analysis for the usability perception of the KNX Trainer platform is at a high level 4.7625. The highest mean score is 4.8542, was obtained by the item PEOU4: The functions and controls of the KNX trainer platform are easy to understand. This analysis has shown that the platform is easy to use by the respondents.

##### iii. Part III: Perceived Usefulness (PU)

Table 8: Analysis of mean score and standard deviation for perceptions of usefulness of the proposed KNX trainer platform

| Code               | Statement Items                                                                                     | Mean Score | Score |
|--------------------|-----------------------------------------------------------------------------------------------------|------------|-------|
| PU1                | The KNX trainer platform improves my understanding of KNX systems.                                  | 4.7917     | High  |
| PU2                | The KNX trainer platform helps me learn KNX configuration more effectively.                         | 4.8750     | High  |
| PU3                | The KNX trainer platform improves my ability to use ETS6 for KNX system configuration.              | 4.7083     | High  |
| PU4                | The KNX trainer platform improves my practical skills in KNX system installation and commissioning. | 4.8542     | High  |
| PU5                | The KNX trainer platform helps me develop my KNX troubleshooting skills.                            | 4.833      | High  |
| Average Mean Score |                                                                                                     | 4.8125     | High  |

Perceived Usefulness (PU) is the degree to which a user believes that using a particular system will enhance their performance, especially in completing tasks more effectively, efficiently, or with better quality (Davis, 1989). The items on the perceived usefulness refer to the respondents' feedback on the effectiveness of using the proposed KNX trainer platform in KNX course as shown in Table 8. The results showed that more than 90% of the respondents agreed with the statements on the first to fifth items. In general, it was found that the respondents' agreement for all items in the perceived usefulness aspect was high and this clearly showed that the proposed KNX Trainer Platform was very helpful in KNX course. PU2 The KNX trainer platform helps me learn KNX configuration more effectively achieved the highest overall score with a mean of 4.8750. Both constructs received overwhelmingly positive scores above 4.5 out of 5, indicating strong user agreement on the utility and accessibility of the platform.

## 5. Conclusion

In conclusion, the proposed modular KNX-based Smart Building Automation (SBA) trainer platform has been successfully developed and validated. It achieves a 100% success rate across all control functions along with reliable and error-free bus communication. The platform effectively bridges local decentralized wired automation with app-based mobile control for enhanced remote management by seamlessly integrating essential KNX components with the GVS Smart ecosystem. Finally, this scalable, cost-effective and mobile platform addresses critical limitations in existing educational tools. By providing a versatile environment for workforce training and serving as a robust and practical testbed for advanced smart building, automation algorithms and IoT research.

**Acknowledgement:** The authors gratefully acknowledge GreenControls Technology Company for providing the components and equipment used in the development of the proposed trainer platform.

**Author Contributions:** The research study was carried out successfully with contributions from all authors.

**Conflicts of Interest:** The authors declare no conflict of interest.

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