journal homepage: https://journal.pktm.com.my/

International Journal of Technical Vocational and Engineering Technology

e-ISSN2710-7094, Vol. 6, No. 2 (2025)

Critical Design Thinking As A Supervisory Framework For Final Year Project Development In Biometric System

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ARTICLE INFO

Article History:
Received 2 July 2025
Revised 16 September 2025
Accepted 24 October 2025
Published 30 October 2025

Keywords:
Critical Design Thinking;
Final Year Project;
Facial Recognition;
Iterative Learning;
Higher Education Supervision.

ABSTRACT

This paper examines the application of the Critical Design Thinking (CDT) framework as a supervisory model for the development of Final Year Projects (FYPs) in technical higher education. Traditional supervision methods, which often emphasize system deliverables and code functionality, tend to overlook the cultivation of reflective thinking and adaptive problem-solving skills crucial for 21st-century engineering graduates. Addressing this issue, the study aims to demonstrate how CDT can foster deeper learning outcomes, enhance student engagement, and promote innovation through structured, reflective, and iterative processes. This study employed a qualitative case study approach at a Malaysian polytechnic, focusing on the supervision of a student developing a facial recognition-based attendance system. The project progressed through the five phases of CDT —empathizing, defining, ideating, prototyping, and testing—under close guidance from the supervisor, who served as a facilitator and co-learner. Data was collected through supervision logs, design journals, performance metrics, and reflective memos. Findings reveal that the system achieved up to 93% accuracy under optimal lighting and proximity conditions. Beyond technical success, the CDT approach contributed to notable gains in student coding proficiency, analytical reasoning, and contextual awareness. The iterative and collaborative nature of the CDT process facilitated timely adjustments to address environmental challenges, such as lighting variability and user interface considerations. The novelty of this study lies in repositioning FYP supervision as a dynamic, co-constructive practice rather than a linear delivery of technical tasks. This provides empirical validation of CDT as a scalable, pedagogically sound framework capable of aligning technical education with both industry expectations and broader societal needs. These insights offer significant implications for curriculum designers, academic supervisors, and institutions seeking to modernize engineering education.

1.0 Introduction

In technical and engineering education, the Final Year Project (FYP) serves as a vital capstone experience, enabling students to apply their disciplinary knowledge to real-world problems. Traditionally, FYP supervision has prioritized technical deliverables, including system functionality, code performance, and the quality of the final report. While these outcomes are important, such an approach often overlooks the development of reflective thinking, contextual awareness, and iterative problem-solving skills that are increasingly essential in the 21st-century workforce. To address these limitations, **Critical Design Thinking (CDT)** offers a student-cantered, inquiry-driven methodology that fosters creativity, critical reflection, and real-world engagement. CDT builds upon conventional design thinking by integrating deeper cycles of ideation, experimentation, and empathy. It encourages learners to co-construct knowledge, challenge assumptions, and adapt their designs in response to real user feedback and environmental constraints (Farrar, 2020; Patel et al., 2024). This research explores the implementation of CDT in the supervision of an FYP involving the design and environmental testing of a facial recognition-based attendance system. The project emphasized collaboration between supervisor and student throughout the five phases of CDT: empathize, define, ideate, prototype, and test. Rather than a linear technical process, the project evolved through iterative cycles of inquiry and reflection, with the supervisor acting as a facilitator and co-designer. By applying CDT to FYP supervision, this study aims to demonstrate how reflective, context-aware learning can be integrated into technical project development. The findings highlight the potential of CDT to enhance student learning outcomes, foster innovation, and strengthen the educational value of capstone projects in higher education settings.

2.0 Literature review

2.1 Design Thinking in Higher Education

Design Thinking (DT) has emerged as a prominent, student-cantered pedagogical framework in higher education, especially within project-based learning and knowledge management contexts. Farrar (2020) demonstrated that integrating DT into biomedical instrumentation courses not only enhances student engagement but also strengthens postgraduate readiness by cultivating real-world problem-solving skills. In the domain of information systems education, DT principles applied during the requirement analysis stage have been shown to deepen students' understanding of user needs, thereby enabling them to design more effective and relevant solutions (Mohamad et al., 2022).

Moreover, DT has been identified as a catalyst for developing students' critical thinking skills, an essential component of 21st-century learning. Maknuunah et al. (2021) found that embedding DT into project-based learning environments positively influenced students' ability to analyse problems and think creatively. Beyond instructional design, DT also serves as a robust knowledge management framework, supporting institutional planning, course development, and faculty resource sharing (Mostofa et al., 2020). These findings suggest that DT offers a holistic approach to supervising final year projects, including those in technical disciplines such as biometric systems, by aligning academic deliverables with industry expectations.

2.2 Integration of Design Thinking and Technological Innovation

Recent scholarship has expanded the application of DT through its integration with emerging digital technologies in educational contexts. Patel et al. (2024) highlighted how the combination of critical thinking and design thinking within design innovation curricula significantly enhances students' cognitive flexibility and problem-solving dispositions. Similarly, Sangeetha et al. (2023) and Gokul Prasad et al. (2023) demonstrated that DT frameworks contribute to the successful development of IoT-based attendance monitoring systems utilizing RFID and facial recognition, leading to improved administrative efficiency and the reduction of fraudulent behaviours. To address challenges associated with supervising a growing number of final-year student projects, Isa et al. (2024) proposed a web-based Final Year Project Management

System prototype. Designed using DT principles, the system offers a centralized dashboard for monitoring progress, streamlining supervision processes, and improving project completion rates. These studies collectively underscore the potential of integrating DT with digital tools to optimize educational management, student tracking, and outcome assessment.

2.3 Design Cognition, Critical Thinking, and Sustainable Innovation

In addition to its technological and pedagogical applications, DT has also been associated with improvements in cognitive development and sustainable education. Aston (2023) reported that workshops focusing on factors influencing critical thinking significantly enhanced international students' analytical skills, particularly in questioning assumptions and applying diverse perspectives. Advancing this focus, Yu et al. (2023) employed biometric measures such as EEG and eye-tracking to explore designers' physiological responses during cognitive tasks, offering objective insights into the mental processes involved in DT activities. Zainal et al. (2024) further validated the efficacy of DT by applying it to IoT project development, where students exhibited improved technical understanding and design competencies. Furthermore, DT has been recognized as a strategic tool for addressing global sustainability challenges. According to Leal Filho et al. (2024), the human-cantered and iterative nature of DT aligns well with the goals of the United Nations Sustainable Development Goals (SDGs), enabling learners to co-create practical, innovative solutions for complex societal problems.

2.4 CDT, CDIO, and Integrated Curriculum Models in TVET

The Department of Polytechnic and Community College Education (DPCCE) has championed curriculum innovation in Malaysian polytechnic education through the implementation of the CDIO (Conceive-Design-Implement-Operate) framework, aiming to develop high-quality, industry-ready TVET graduates. CDIO emphasizes real-world product and system development, combining technical mastery with soft skills like communication, teamwork, and problem-solving—paralleling the objectives of Critical Design Thinking (CDT). Notably, the DPCCE introduced three integrated curriculum models: Initiatives such as Intra-programme (IntraIC), Inter-programme (InterIC), and Inter-institutional collaboration (3IC) enable educators to embed 21st-century competencies within core technical modules without increasing credit loads or placing additional burden on students (Kamarudin, 2022).These integrated curriculum approaches promote interdisciplinary teamwork, reduce redundant assessments, and facilitate experiential learning aligned with 4IR demands. Like CDT, these models emphasize stakeholder engagement, project-based learning, and reflective practice. The synergy between CDT and CDIO frameworks suggests that embedding critical and design thinking within structured project supervision can address persistent gaps in soft skill development while maintaining technical rigor.

3.0 Methodology

This study employed a qualitative case study approach to examine the implementation of the Critical Design Thinking (CDT) framework in supervising a Final Year Project (FYP). The case cantered on a single student project in a Malaysian polytechnic, which involved developing and testing a facial recognition-based attendance system in diverse environmental conditions. The CDT framework structured the project into five iterative phases: empathize, define, ideate, prototype, and test, while emphasizing collaboration, reflection, and context-aware design. The case study design was selected for its ability to capture in-depth, contextual insights into how CDT influenced the student's learning experience and the supervisor's facilitative role. This approach aligns with the interpretivist paradigm, which values subjective understanding, co-construction of meaning, and process-oriented inquiry (Merriam & Tisdell, 2016). Supervision was explicitly framed around the CDT model, with **weekly meetings** functioning as structured checkpoints for each design phase. During these sessions, the supervisor and student collaboratively engaged in **documentation review, brainstorming, interface coding, prototype testing**, and **reflective evaluation**. Each CDT phase was systematically applied to guide the project’s progression, ensuring that both technical and experiential learning outcomes were achieved.

3.1 Empathize: Understanding Real-World Needs

In the Empathize phase of the Critical Design Thinking (CDT) framework, the development of the Visitor Face Recognition System (VFRS) was grounded in a deep understanding of user experiences and contextual challenges. Under the guidance of the supervisor, the student engaged in systematic observation and direct interactions with key stakeholders, including **security personnel, lecturers, administrative staff, and students**. The supervisor facilitated access to these groups and played a crucial role in shaping the inquiry process by encouraging the student to focus on **pain points derived from actual field conditions** rather than theoretical assumptions.

One of the most evident issues emerged from the traditional visitor logging method, as illustrated in *Figure 1: PSAS Visitor Check-in Book*. The handwritten entries were frequently **illegible**, **inconsistent**, and vulnerable to **intentional or unintentional errors**, undermining the integrity and security of institutional visitor records. Through these engagements, several critical user insights were identified:

i. A **strong demand for contactless solutions**, particularly in response to post-pandemic health protocols.

ii. **Frequent inaccuracies** and loss of accountability in manual attendance tracking systems.

iii. **Concerns about traceability** due to the absence of clear visit purposes or structured data fields.

iv. **Environmental constraints**, such as poor lighting conditions, which impacted the performance of biometric recognition tools.

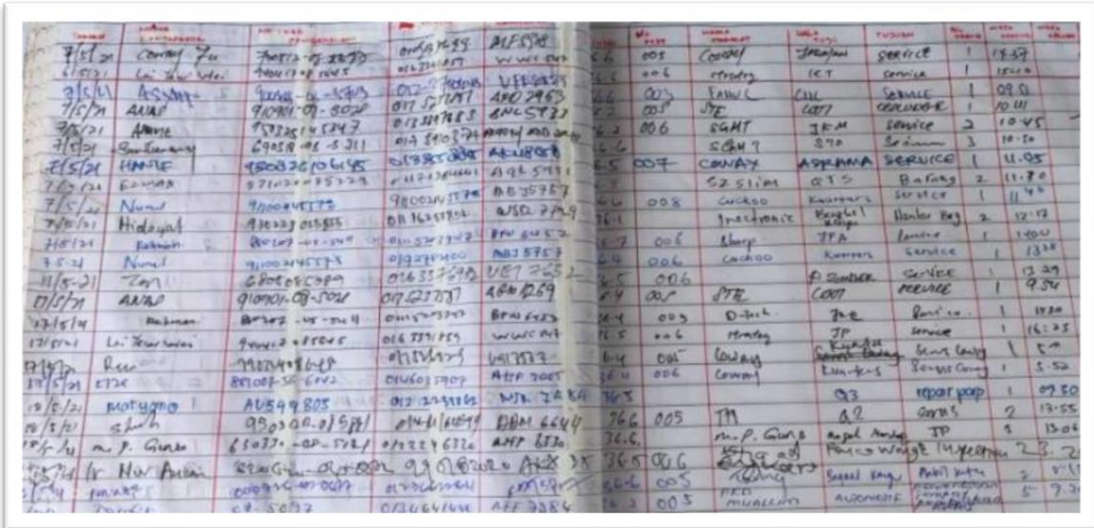

Figure 1.1: PSAS Visitor Check in Book

These insights were further validated through repeated user dialogues, on-site walkthroughs, and reflection checkpoints led by the supervisor. By guiding the students through this exploratory process, the supervisor helped ensure that the foundational design decisions were rooted in **empathy, practicality, and direct stakeholder needs**. Consequently, the system was envisioned to eliminate manual entry errors, enable real-time digital visitor tracking, and incorporate **cloud-based data storage** as a safeguard against the loss of physical records. This user-centric understanding laid a solid groundwork for the subsequent CDT phases of Define, Ideate, Prototype, and Test.

3.2 Define: Co-Constructing the Problem Statement

Supervisor and student collaboratively framed the central research challenge:

"How might we improve the accuracy of facial recognition attendance systems under diverse lighting, background, and distance conditions?"

Weekly review sessions were used to validate testable variables and align technical feasibility with academic expectations.

3.3 Ideate: Designing Creative and Contextual Experiments

The ideation phase involved brainstorming sessions around:

- Algorithm options (e.g., LBPH vs Haar Cascade).

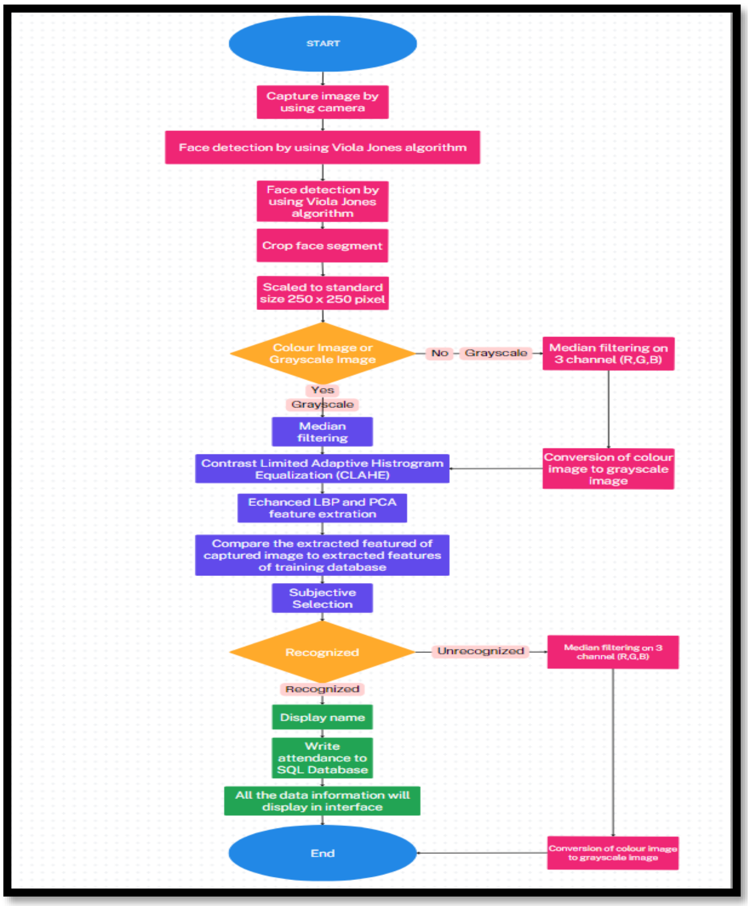

Figure 1.2: Flowchart of Face Recognition System Connect with Dashboard

- Testing environments (indoor vs outdoor).

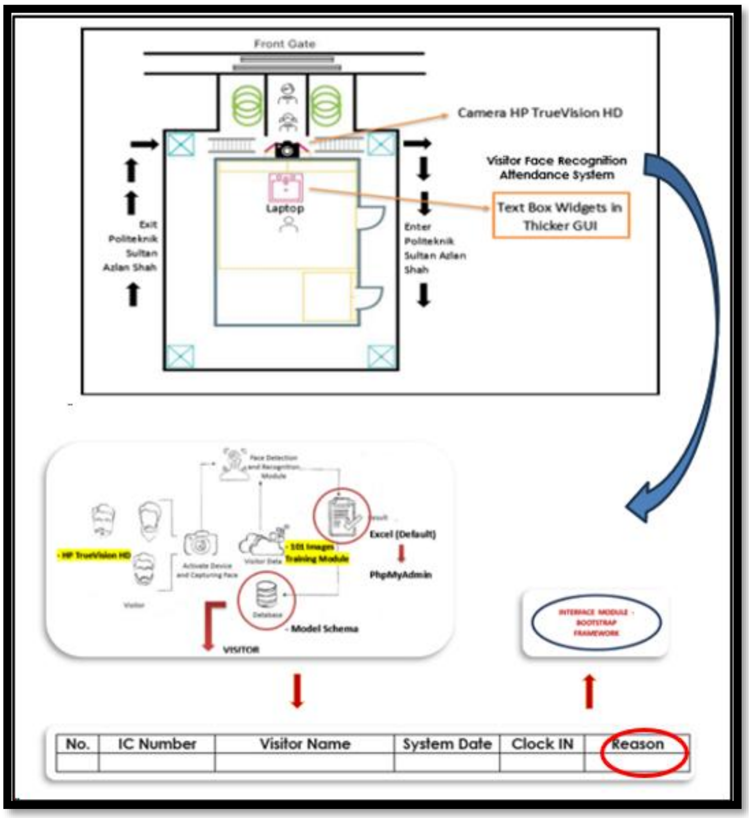

Figure 1.3: Block Diagram for the Face Recognition System

- Image training conditions (bright vs dim lighting).

Literature reviews and design sprints helped generate diverse ideas, while supervisor feedback ensured the ideas remained research-valid and testable.

3.4 Prototype: Building the System through Iteration

The student developed a Python-based facial recognition prototype using OpenCV, deploying the system in both indoor (PSAS guard house) and outdoor (PSAS main gate) environments.

i. First Iteration: Default lighting and background.

ii. Second Iteration: Adjusted for lighting intensity and background complexity.

Visitor Face Recognition System Operation Process

Figure 1.4: Visitor Face Recognition System Operation Process

The supervisor's input included debugging support, dataset standardization techniques, and feedback on detection accuracy metrics.

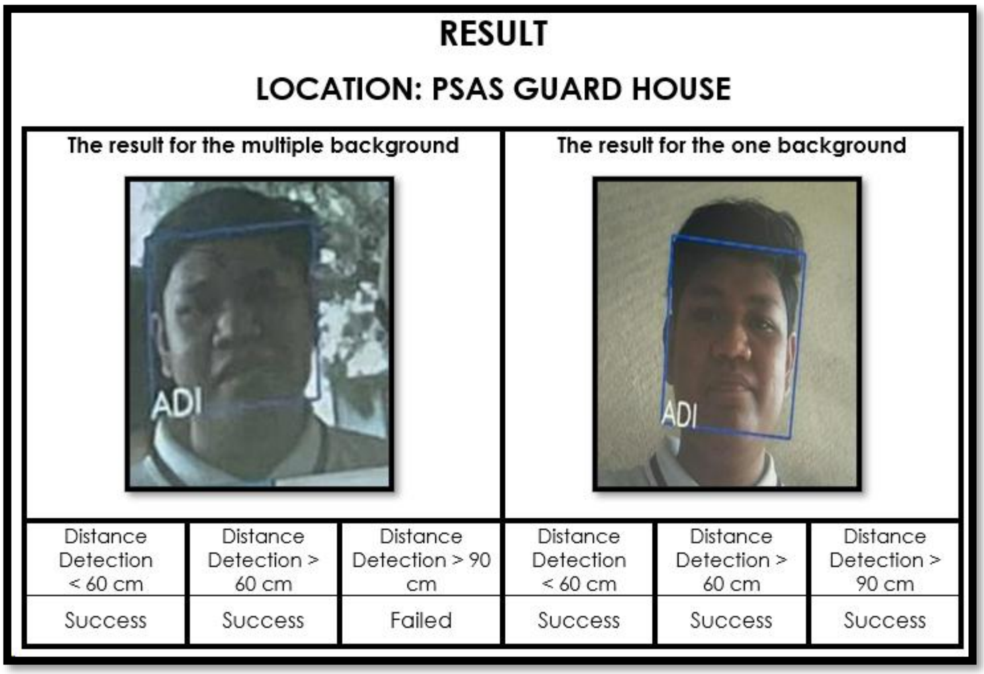

Figure 1.5: Visitor Face Recognition System Performance Results in Multiple Environmental Scenarios

3.5 Test: Reflective Evaluation and Result Interpretation

Testing was done in multiple environmental scenarios. The supervisor and student jointly interpreted the results, emphasizing critical reflection on failure cases:

Table 1.1: Summary of Environmental Factors and Their Observed Impact on Facial Recognition Accuracy

Factor	Key Observation
Lighting Intensity	High-intensity images improved accuracy >90%.
Background Uniformity	Uniform settings reduced false negatives.
Face-to-Camera Distance	60–90 cm optimal; beyond that saw drop-offs.

The testing stage aligned with CDT's goal of converting problems into insights through hands-on validation and reflective discussion.

4.0 Discussion of analysis and findings

The project outcomes were organized based on the five phases of the CDT framework, with performance data and learning reflections analysed in tandem. Quantitative testing outcomes and qualitative observations from supervision meetings are presented below.

4.1 System Performance Across Environmental Variables

Table 1 summarizes the facial recognition system's accuracy results under varied environmental conditions:

Table 1.2: System Accuracy by Environmental Condition

Variable	Condition	Accuracy Rate
Lighting Intensity	High (outdoor, sunlight)	92%
	Low (indoor, evening)	74%
Background Uniformity	Plain background	89%
	Complex background	68%
Face-to-Camera Distance	60–90 cm	93%

Variable	Condition	Accuracy Rate
	>100 cm	65%

The testing phase indicated that recognition accuracy was highly sensitive to lighting intensity and the distance between the face and the camera. The most accurate results were obtained under well-lit, uniform-background conditions with the camera positioned 60 to 90 cm from the subject.

4.2 Reflective Learning Through CDT Phases

Each CDT phase supported specific learning outcomes and decision-making:

i. Empathize: Field interviews uncovered user concerns related to hygiene (particularly in the post-COVID context), inaccuracies in manual attendance tracking, and congestion at security checkpoints. These findings were instrumental in narrowing and clarifying the scope of the project’s core problem.

ii. Define: The supervisor and student formulated a clear, actionable research question focused on optimizing biometric accuracy under realistic conditions.

iii. Ideate: Brainstorming sessions led to the exploration of algorithm types (LBPH, Haar Cascade), testing environments, and controlled lighting manipulation.

iv. Prototype: Iterative development cycles enhanced the student’s coding skills, system debugging strategies, and understanding of image datasets.

v. Test: Quantitative results were jointly interpreted, with the supervisor guiding reflection on false positives, variable control, and experimental reliability.

4.3 Conclusion and Future Research

This study demonstrates that applying the Critical Design Thinking (CDT) framework in FYP supervision offers significant pedagogical and technical benefits. The CDT process supported deeper student engagement, collaborative decision-making, and iterative learning all critical attributes for future engineers and technologists.

4.3.1 Enhancing Learning Outcomes

By engaging the student in real-world problem identification, system prototyping, and reflective testing, CDT transformed the FYP into a learning journey. The student developed:

i. Stronger analytical reasoning skills when comparing test conditions.

ii. Improved coding proficiency through iterative development.

iii. Greater confidence in evaluating experimental limitations and interpreting accurate metrics.

These outcomes align with previous findings by Farrar (2020), Maknuunah et al. (2021), and Patel et al. (2024), who emphasized the value of DT frameworks in building higher-order thinking and practical problem-solving skills.

4.3.2 Redefining the Supervisor’s Role

The supervisor's role evolved from evaluator to facilitator and co-learner. Weekly checkpoints and Socratic questioning helped the student challenge assumptions, revisit design flaws, and make informed modifications. This dynamic reflects the findings of Aston (2023) and

Isa et al. (2024), who highlighted the critical role of reflective practice and dialogic supervision in enhancing learning within technical education contexts.

4.3.3 Bridging Technical Design and Real-World Contexts

Through CDT, the project addressed not only system functionality but also contextual deployment issues such as lighting constraints, background complexity, and user accessibility. These results suggest that CDT offers a scalable framework for aligning technical outcomes with environmental realism and user needs, as also argued by Zainal et al. (2024) and Leal Filho et al. (2024).

4.3.4 Alignment with CDIO and TVET Graduate Outcomes

The findings from this CDT-supervised FYP project resonate with broader educational strategies implemented in Malaysia's polytechnic and community college systems. As highlighted by Kamarudin (2022), the DPCCE's integrated curriculum models, particularly IntraIC and InterIC have proven effective in enhancing students' communication, critical thinking, and project coordination skills without extending academic timelines. Likewise, the implementation of the CDT framework in this study facilitated both the technical advancement of the biometric attendance system and the development of the student's adaptability, reflective thinking, and capacity for real-world problem-solving. The alignment between CDT and CDIO approaches suggests that technical supervision can be more impactful when grounded in holistic, interdisciplinary learning models. The shared focus on co-construction, iterative development, and stakeholder engagement positions both frameworks as powerful tools in cultivating graduates who are technically proficient, socially responsible, and industry ready. Embedding CDT within FYP supervision thus complements national TVET reform goals and supports Malaysia's aspiration to develop agile, employable graduates in the era of digital transformation and sustainability.

5.0 Conclusion and Future Research

This case study illustrates the effectiveness of the Critical Design Thinking (CDT) framework as a supervisory approach for Final Year Projects (FYPs) in technical education. By embedding iterative learning, contextual experimentation, and reflective supervision into the project process, CDT helped the student move beyond product-focused outcomes toward deeper conceptual understanding and adaptive design skills. By integrating the five phases of CDT empathize, define, ideate, prototype, and test, the supervision process was transformed into a collaborative, reflective, and iterative learning experience. The student engaged directly with real-world user needs, designed context-sensitive solutions, and iteratively refined the system based on environmental challenges and empirical testing. Rather than focusing solely on technical outputs, the project fostered conceptual understanding, design adaptability, and critical thinking. The supervisor's role as a facilitator further supported shared inquiry and structured reflection, contributing to deeper learning and greater innovation. The findings affirm that CDT not only improves technical competencies but also nurtures higher-order thinking, problem-solving resilience, and self-directed learning. As technical education continues to evolve in response to complex industry and societal challenges, incorporating CDT into FYP supervision represents a meaningful step toward preparing graduates who can design, critique, and adapt technology with purpose.

Acknowledgements

We would like to express our sincere gratitude to our dedicated team members for their hard work, commitment, and collaboration throughout the development of this project. Their efforts in research, design, and implementation have been instrumental in ensuring the success of the Visitor Face Recognition Attendance System. We also extend our heartfelt appreciation to the Head of the Electrical Engineering Department, Polytechnic Sultan Azlan Shah, for their continuous support, guidance, and encouragement, as well as the provision of necessary resources that greatly contributed to the completion of this project.

Author Contributions

Rahmat N.: Conceptualization, Methodology, Supervision, Data Curation, Validation, Writing- Original Draft Preparation; **Ahmad H.**: Writing-Reviewing and Editing; **Seng S. Y.**: Methodology, Software, Data Curation; **Dwiny Meidelfi**: Writing-Reviewing

Conflicts of Interest

The manuscript has not been published elsewhere and is not being considered by other journals. All authors have approved the review, agree with its Submission, and declare no conflict of interest in the manuscript.

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