Rihla: A Digital Twin for Smoother Pilgrim Journeys at Hajj Air Hubs

كلية الحاسبات وتقنية المعلومات
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1 Abstract

Hajj air hubs move huge crowds on tight schedules: in 2025, Madinah's Prince Mohammed bin Abdulaziz Airport received **719,400 pilgrims**, 49% of all pilgrims arriving by air. Yet the data that could keep this flow smooth (sensors, cameras, building systems, bus and flight schedules) sits in separate silos, so problems are handled after they happen. **Rihla** is a digital twin of the pilgrim journey, built on **DigiTwin**, our reusable base twin that brings a facility's data into one live 3D model, analyses it for monitoring, prediction and alerts, and is specialized through configuration rather than new code. Using a design-science approach, we reviewed 20+ research sources and produced the requirements, system architecture, UML models, data store design (PostgreSQL + TimescaleDB) and an operator dashboard. Rihla applies this base to the **pilgrim departure journey**, from housing to bus yard to terminal, to be built and validated in 2027.

2 Introduction

Every Hajj season, pilgrims move between housing, buses, terminals and flights on fixed dispatch schedules; a delay at one step backs up every step after it.

A digital twin is a live virtual replica fed by real-site data, letting operators see the whole facility and act before problems grow. Most twins are built for one building and cannot be reused. Rihla closes this gap with a reusable base, in line with Vision 2030's digital transformation goals and the Pilgrim Experience Program.

3 Objectives

- Design a facility-agnostic base twin that unifies sensors, cameras, building systems and schedules into one live model.
- Add analysis on top: monitoring, crowd and load forecasting, and alerts before limits are crossed.
- Build Rihla: specialize the base to the pilgrim departure journey at Madinah airport through configuration, not new code.

4 Methodology

Study design
Design-science study at FCIT, KAU. Design phase in Fall 2026 (Senior Project I); build and validation in 2027 (Senior Project II).

Evidence & target site
20+ digital twin research sources, each checked with the PROMPT quality criteria. Target: a Hajj air hub receiving 719,400 pilgrims (Madinah, 2025).

Data collection
Literature review, requirements and use-case modelling. Twin inputs: sensors, cameras, building systems, bus and flight schedules.

Analysis & tools
UML models (class, sequence, activity, state); PostgreSQL + TimescaleDB for time-series data; forecasting and rule-based alerts; 3D game-engine view.

5 Results

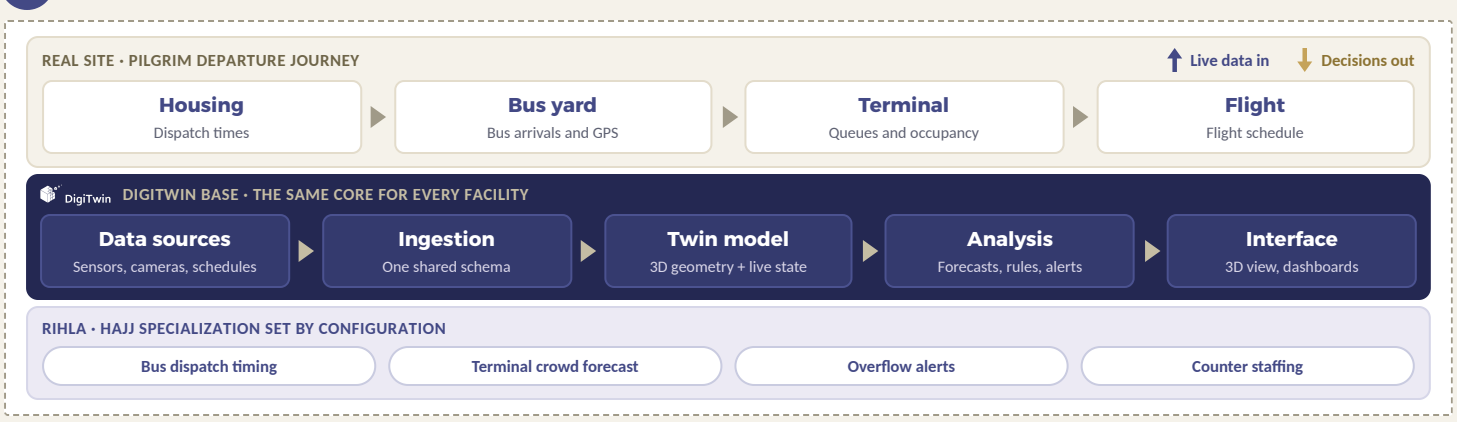


Figure 1. Rihla on the DigiTwin five-layer base (design-phase result): data flows up from the site; decisions flow back.

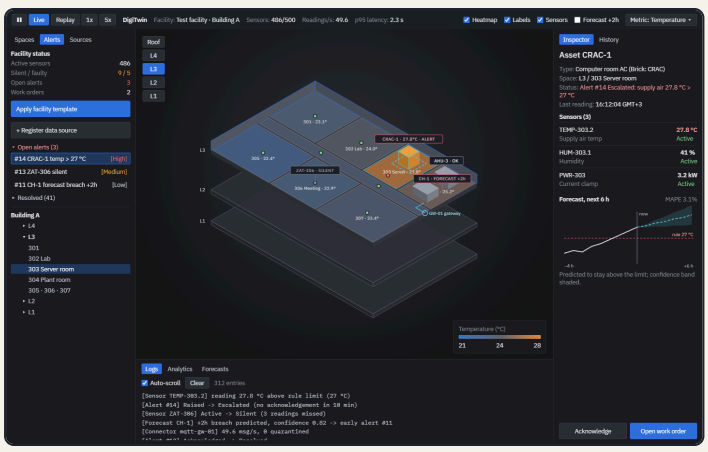


Figure 2. DigiTwin operator dashboard (mock-up, sample data). Rihla reuses it for terminal zones.

49% of pilgrims arriving by air came through Madinah airport (2025)

50% of a full twin's components covered by even the best general platform (11 of 22)

25% of building-twin case studies measured a real gain (5 of 20)

6 Discussion & Recommendations

TwinArch shows one twin design can span every domain, but its 20 expert reviewers rated it lowest on usability: too abstract to apply. ExaDigiT shows reuse through configuration files works. Our DigiTwin base sits between them: general across facilities, concrete enough to build. Only 5 of 20 case studies measured a gain, so we plan validation from day one.

Recommendations

- Pilot at one Hajj terminal: link bus dispatch to flight times and live terminal occupancy.
- Reuse the base for other Hajj hubs (Jeddah Hajj Terminal, Haramain stations, Mashaer) and add AI crowd forecasting.

7 References

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