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ADDRESSING WORKPLACE MANAGEMENT CHALLENGES WITH A SYSTEM ENGINEERING APPROACH TO DIGITAL TWIN ENVIRONMENTS

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Abstract

To address challenges related to Workplace Management practices, this study leverages System Engineering and Digital Twin Environments principles, proposing a Workplace Asset Management System (WAMS). The methodology spans stakeholder requirement analysis, use case formalization and system architecture design, aiming to validate the structure of a unified environment for multi-domain data integration and stakeholder collaboration, focused on optimizing workspace allocation via data-driven insights. Through the adoption of Semantic Web technologies, the proposed system aims to foster digitized and scalable holistic approaches in Asset Management. While acknowledging limitations, a pilot is being implemented, to demonstrate benefits at organizational and technical level.

Introduction

A perspective on Workplace Management

Under the lens of this study is the creation of value inside large organizations through efficient Asset Management (AM) processes. Given the definition of Assets as both tangible and non-tangible entities, entitled to deliver value along their lifecycle (ISO, 2014), this investigation focuses on managing office spaces, further on also called workspaces, as well as human resources and workplace-related equipment. The overarching goal of the research is leveraging organizational needs and challenges to suggest a digital framework or system, capable of efficiently tackling those requests.

Right after the Covid-19 pandemic, with the digitalization of work, an increased interest on understanding and improving the way organizations, buildings, and people interact arose, leading to holistic and transdisciplinary research approaches (Tagliaro et al., 2023). Although not yet formalized as an independent discipline, the study of Workplace Management (WM) started in the 1990s and is seen as the intersection of multiple organizational stakeholders, but mainly taken care of by Facility Management (FM), Corporate Real Estate Management (CREM), or Human Resource Management (HRM) departments. Recent literature defines WM as a *"collaborative task towards aligning the workplace with the organization and the employees using it"* (Danivska and Appel-Meulenbroek, 2021). Not only it requires knowledge from multiple disciplines, being fragmented and sector-specific, but it is also influenced by many social and political factors changing over time (Danivska and Appel-Meulenbroek, 2021). Those can be traced back to adverse macro-economic contingencies arisen in the latest years, including the increase in electricity prices, the intensification of remote working practices, or the prescription of European regulations to reduce CO2 emissions, which led building managers to rethink their real estate and space occupancy strategies. They are also more oriented toward a user-centred approach when re-thinking such strategies, with a focus on flexible working policies benefitting workers' wellbeing. At their advantage, cluster analysis (Migliore and Rossi-Lamastra, 2023) helps to understand how different workers' groups appreciate and perform in different work environments, eventually optimizing workers allocation and work-from-home policies based on their tasks relatedness. ICT-induced New Working Practices (NWPs) have recently demonstrated benefits related to operational cost reduction via reduced space usage and to enhanced business performance (Jayantha and Oladinrin, 2019). Altogether, these considerations would impact CRM strategies, leading to consider leasing or selling underutilized spaces, relocating premises to better suiting buildings, or optimizing energy efficiency based on occupancy patterns. Current scientific advancements take on the request for evaluating alternative uses of workspaces, accommodating dynamic occupant needs via adaptive architectural components, and developed agent-based simulation frameworks to automatically evaluate the most appropriate strategies amidst possible scenarios (Drusinsky et al., 2024).

In a real-world setting, WM challenges have to be studied as a whole, and not merely as a sum of parts, as they derive from the intersection of multiple domains: from FM, involving the traceability of building spaces and of physical assets here located (equipment, devices, laptops), so to ensure their operational steadiness across their life cycle, to HRM, accounting for employees status and comfort in the workplace, as to Asset Information Management (AIM), in order to properly store and use information related to such assets from an IT perspective as well.

Towards Digital Twin Environments

The need of a strategic business approach for an effective yet collaborative management of assets can be traced back to the conceptualization of Product Lifecycle Management (PLM), defined as *"an attempt to 'de-silo' the data of various functional areas and create autonomous objects that carry the information of their real world counterpart"* (Grieves, 2005b) and further extended by literature into the concept of Asset Lifecycle Management (ALM) (Altamiranda, 2024). Moving from a function-centric to a product-centric, nonetheless holistic approach, the idea of Digital Twin (DT) was derived, up to latest advancements. This lead towards the integration of Artificial Intelligence (AI) in so-called Intelligent Digital Twins (IDT), which aim to have an active, online, goal-seeking and anticipatory behaviour (Grieves, 2022). Focusing on the operational stage of products, the purpose of an IDT is related to performance issues and constitutes the basis for simulations and analyses on an asset's virtual counterpart, therefore enabling stakeholders to digitally mirror and manage an asset along its lifecycle (Dietz and Pernul, 2020). In the built environment, researchers are pointing towards integrated cognitive technologies and automated knowledge management for transforming data into practical knowledge (Ozturk, 2021). They do so by investigating the implementation of Cognitive Digital Twins (CDTs), meant to autonomously and dynamically react to environmental changes (Meschini et al., 2022), and of Semantic Digital Twins (SDTs), which apply Semantic Web technologies to incorporate heterogeneous building information to BIM models (Boje et al., 2020, Donkers et al., 2022).

The adoption of an enterprise-wide system supporting managerial and decision-making practices can be seen as a Digital Twin Environment (DTE), where previously separated multi-domain data (Dietz and Pernul, 2020) and applications are integrated, operating on one or multiple Digital Twin Instances (DTI) (Grieves and Vickers, 2017), for a variety of purposes, depending on organizational needs. Challenges in decision processes are often related to siloed storage of heterogeneous data sources, hence the scope of a DTE is related to replacing document-centred methods of system technology with model-based ones (Wang et al., 2021), leveraging interconnected machine-readable data. Among the goals of PLM and DTs is the logical grouping of distributed data elements, including the virtual counterpart of physical assets, adopting database technology that is more flexible in structure and content type, as well as adaptable over time (Grieves, 2005b). Implemented examples in the built environment show how combining Knowledge Discovery in Databases (KDD) with cross-domain Semantic DTs, exploiting Linked Building Data (LBD), succeeds in integrating heterogeneous data sources, such as those capturing sensor data and occupants' experiences in buildings, then enabling occupant-centric decision-making processes and Post-Occupancy Evaluations (POE) during their operational phase (Petrova et al., 2019, Donkers et al., 2022, Bruttini et al., 2023).

To tackle the early phases of a digital product development and outbalance existing sources of uncertainty, Model Based System Engineering (MBSE) can provide structured guidelines to the process (Nielsen et al., 2015; Wang et al., 2021). It helps acquiring user requirements and architectural characteristics of the system with a shared and collaborative overview on the product development process (Grieves, 2005a).

With the scope of engineering a DTE to facilitate decision-making on optimal workspaces allocation, the distinction between processes and practices should be pointed out. While processes are standardized and controlled sequences of steps with plainly declared inputs and outputs, practices are organizational routines driven by subjectivity but holding the potential for change (Feldman and Pentland, 2003, Grieves, 2005a). Trying to bridge the gap between processes and practices, the use of DTEs would make explicit pertinent information when needed, redirecting managers' attention to where they are required to apply their judgement. Moreover, a DTE, thanks to its holistic approach, paves the way to the integration of objective quantitative data with stakeholders' subjective opinions, periodically capturing *"the quality of the relationship between buildings and people"* (Tagliaro et al., 2023), actively including the human factor into decision processes.

Aims and Objectives

From an organizational perspective, this study aims to suggest a solution to the inconsistent and time-consuming nature of traditional workspace management tasks, mainly related to properly allocating employees to office spaces, optimizing space use and team collaboration. From a technical standpoint, it proposes a DTE for WM, in terms of high-level System Architecture, enabling use case objectives and minimum requirements to shape an insightful descriptive layer, which guides decision-making practices. This proposition is based on DT principles and uses a System Engineering (SE) methodology. Technological advancements in the built environment sector and recommended practices from literature are considered, referring to interoperability, data quality and openness, semantic consistency and knowledge extraction. The presented DTE, referred to as WAMS (Workplace Asset Management System), is meant to guide the use and adoption of KG-based systems for AM tasks in the built environment. It serves as an example to foster the development of systems with multi-domain monitoring capabilities and their gradual implementation, driving organizations towards a digitized and holistic approach (Boscariol et al., 2024) to PLM. Insights about the impact on managerial processes, but also challenges and limitations are then discussed, giving space for future research work.

Conceptual framework

System Engineering method

Following SE principles with a model-based approach helps to systematically identify challenges and objectives of the scoped field, along with modelling activities and tools capable of satisfying expressed needs. Gathering requirements involves collaboration between system developers, stakeholders, and end-users. In fact, it is crucial to understands clients' and users' needs, especially in terms of functional requirements, but also to consult with IT and security specialists regarding non-functional requirements, to set expectations for performance and load, or to define the best practices for data protection. Moreover, adopting SE enables to break down domain-related processes, identifying discrete steps and ad-hoc solutions for their improvement, with a modular and scalable approach.

To properly identify System Requirements, interviews with intended users help to elicit what they want to accomplish with the system and what functionalities the latter should have to satisfy those wants. After defining the user personas by their roles (who they are), goals (what they want to do) and motivation (why they want to do it), it is easier to concentrate on user-system interactions, adopting a Use Case (UC) methodology. Through UML UC Diagrams, it was possible to describe every situation in which a user persona interacts with a specific system feature, as it might be 'logging in' or 'the input of asset-related information', focusing on key scenarios. A UC Description narrates the flow of events, explaining the steps that the user takes to interact with the system and the system's responses to those steps, enabling the formalization of a UML Sequence Diagram. This graphical representation shows the interactions between system components over time, depicting the flow of messages between objects and the order in which those messages are sent and received.

Exploiting elicited requirements and formalized workflows guides the schematization of an event-based System Architecture (SA) built on enterprise data assets, where its scope is extracting insights that improve decision-making processes. The comprehension of the domains concerned is crucial, involving close collaboration with stakeholders and domain experts to align conceptual modelling of core concepts with the organization strategic objectives.

Stakeholder requirements

In the context of SE, the identification of stakeholders is crucial to understanding how they affect or are affected by the system, clarifying needs, requirements and relevant perspectives for developing a system that meets its intended purpose (Altamiranda, 2024). The formalization of this study adopts a real-world scenario, trying to answer to the wants of a university as large organization dealing with the management of its administrative office spaces. The stakeholder composition included, in the first place Organizational Units (OU) Managers, in charge of allocating employees to teams and workspaces, but also employees of the Facility Management (FM), Human Resources (HR) and Information and Communication Technologies (ICT) Organizational Unit, as end users performing data insertion tasks regarding assets concerned by their work tasks. A set of individual interviews to involved stakeholders was conducted, aiming to bring together multiple perspectives. Interviews with these professionals provided inputs to develop requirements on how the system shall operate, aligning with business strategies for occupancy optimization.

It emerged that the system should have the scope of providing end-users with a convenient and up-to-date way to optimize the allocation of workers and workspaces, adapting to contingent organizational needs. Through the WAMS, OU Managers must be able to perform such allocation tasks based on informed decision-making processes. They must be able to access insightful details about spatial consistency of available spaces and team-related information about employees thanks to a friendly User Interface (UI) and in a unified platform, without having to physically inspect a building and collect fragmented pieces of information. Additionally, the system shall provide them with a range of features and functionalities that are not available through traditional consultation of siloed databases and documental resources, such as querying spaces by their attributes, resulting in dynamic and interactive visualizations.

This preliminary investigation led to the formal definition of two types of requirements, Functional and Non-Functional Requirements, whose purpose is to clearly identify what the system should accomplish. Functional Requirements are mandatory features specifying the tasks of the system, without which it cannot function properly, and its desired behaviour. They are mainly related to data processing, inputs and outputs, audit tracking, authorization levels, business rules, regulatory requirements, reporting and notification. A table of 35 requirements has been extracted, concerning features as effortless log-in procedures and authentication protocols based on enterprise credentials; visualization of sensible data visibility to managerial roles; capability of logging into the system new rooms, employees and physical assets, with all related attributes; assigning employees to offices; tracking start and end date of assets allocations; displaying building spaces through list, 2D and 3D visualizations; linking on those visuals details about allocated employees and assets; provide multiple visualization pages, including filtering and query capabilities, which leverage the graph database on the backend; and further search and visualization requests based on the case study investigated.

Non-Functional Requirements define how certain system features should look and operate, to grant end-users expectations and needs. They are more user-oriented and subject to System Usability Tests, as per ease of use, reliability, error handling, speed or quality. These requirements converged in a table of 15 entries, prescribing, for example, a fast and reliable performance when searching and querying the system; a user-friendly interface, with a clear to navigate and responsive design; a lightweight application, compatible with devices with reduced computational resources; compliance with local labour regulations and constant update of defined constraints; compliance with GDPR to safeguard users' personal data; reasonable response time, load and refresh rates; the ability to handle many concurrent users during working hours, without having any performance challenges; or the need of minimal effort to update the SA or documentation.

System behaviour formalization

The formalization of a UC Diagram serves to show the different actors (i.e., users or external systems) that interact with the system, as well as the different UCs and their relationships, schematizing the expected performance. Relatively to the implementation of the WAMS, the identified key UCs (*Figure 1*) refer to the followings:

1) Log in: Allows users to enter the system with enterprise credentials and perform predefined actions, based on restrictions defined by the organizational role.
2) “Load Data” Package: Allows Technical Employees to load new data regarding their specific field of interest.
    a) Load Buildings: Allows FM Employees to insert data about Building Spaces.
    b) Load Furniture: Allows FM Employees to insert data about Furniture Assets.
    c) Load ICT Assets: Allows ICT Employees to insert data about ICT Assets.
    d) Add Employee: Allows HR Employees to insert data about Employees, their role and affiliation.
        i) --<include>-- Log in: Allows Technical Employees to access the system visualizations dedicated to their field of interest, based on access control policies.
3) View Occupancy: Allows all Technical Employees and OU Managers to check occupancy and allocation details about office spaces from floorplan and list visualizations.
    i) --<include>-- Log in: Allows actors with organizational authentication credentials to access allocation floorplans, but the amount of information displayed depends on access control policies defined by the user’s organizational role.
4) Allocate Employee to Workspace: Allows OU Managers to allocate Employees to Office Spaces, based on informed decisions made upon visualizing Occupancy reports, where they also verified if employees are assigned the necessary working equipment, in terms of furniture and ICT assets.
    i) --<include>-- Log in: Allows only OU Managers to access the system visualizations dedicated to employee-to-space allocation tasks, based on access control policies.

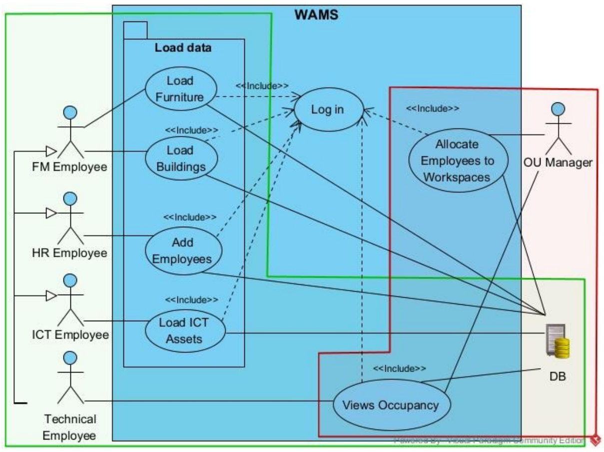

Figure 1: UML Use Case Diagram: “Load Data” Package (green boundary) and Allocate Employee to Workspace (red boundary)

Grouping actors per their organizational role led to the definition of two key use-case scenarios, as represented in *Figure 1*. The UC *“Load Data” Package* sees Technical Employees, representing a generalization of the roles of FM Employee, HR Employee, ICT Employee, as main actors involved. This UC allows Technical Employees to load all necessary data relevant to their competence domain into the system, through dedicated UI visualizations sending those data into the system database. Such data are used to update reports dedicated to space occupancy, enabling intended users to make informed decisions about workspace allocation, by viewing workspaces, related details and occupancy levels. Preconditions to the execution of this UC are that the Technical Employee must log into the system with organization access credentials, and that the organizational databases must be structured accordingly to agreed data schemas and semantics.

The basic flow of events for this UC is representable via a dedicated Sequence Diagram (*Figure 2*) and can be narrated as follows:

- The Technical Employees have access to dedicated visualizations for data insertion on his domain of interest (presented as alternative flows): FM, therefore the spatial consistency of facilities and their identification codes, as well as furniture assets with inventory identifiers; HR, therefore data regarding employee identification, organizational role and affiliation; ICT, therefore technological equipment in use with inventory identifiers.
- Data insertion visualizations send data to the database connected in the backend of the implemented system, updating it. Such updates are sent back to the system, which shows up-to-date visualizations.

- Any Technical Employee can access Occupancy reports, which display floorplans of selected buildings, with listing of office spaces here located, enabling further interrogation of those spaces. They can select a single space from the floorplan or from the list, to visualize detailed information regarding it. They can also query, via predefined filters, office spaces depending on occupancy levels or on their allocation to OUs and employees.
- The visualization pages are published on the organization web server with access control restrictions based on organizational roles of employees, so that Technical Employees only have access to non-sensitive data.

As a result, all relevant data are successfully linked to the generated visuals, delivering up-to-date meaningful insights.

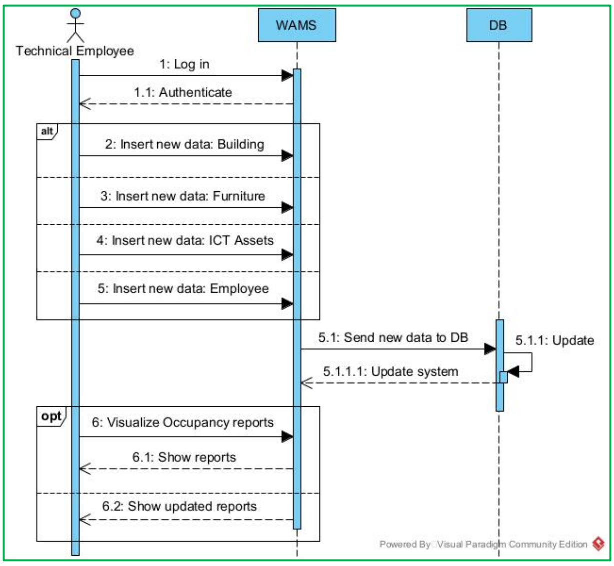

Figure 2: Sequence Diagram of the Use Case "Load data" Package

The same method, including representing the flow of events through a Sequence Diagram, is applied to describe the UC *Allocate Employee to Workspace*, which involves the OU Manager as main actor. This UC allows him to allocate employees of his own OU to available workspaces, based on informed decisions made upon viewing spatial information, occupancy levels, physical assets availability and teamwork relationships to be preserved. Consequently, the successful insertion of such information through the system automatically updates all interactive visuals on Workspace Allocation.

System components

The SA framed for the DTE proposed (*Figure 3*), reflects the structure of a web application, aimed at answering stakeholder needs. Its use is event-driven, being related to the previously presented UCs, involving the visualization of analytical reports and the insertion of new data, either for more technical or decision-making tasks. It aims to support the exchange of data across domain data sources, while delivering contextualized information for knowledge extraction on the end-user side.

DTEs are enterprise-oriented and require the integration of four core blocks (Dietz and Pernul, 2020), outlining the basic structure of the System Architecture:

- Data, of diverse format and content (static or dynamic, documental, sensor-based, regulatory, etc.) relevant to virtually represent the asset.
- Semantic technologies, describing the relations between data elements to provide agreed understanding on their meaning and enable further inference.
- Analysis and simulation tools, to support monitoring, prediction or optimization functionalities, eventually in an automated manner.
- Interfaces and access control, acting on the bidirectional connection of physical and virtual counterparts, enabling data sharing and synchronization.

The organizational dimension is contemplated in terms of authentication and privacy policies, managed through an access control module, but also through the adoption of ontologies, which guide the semantic alignment of enterprise data sources.

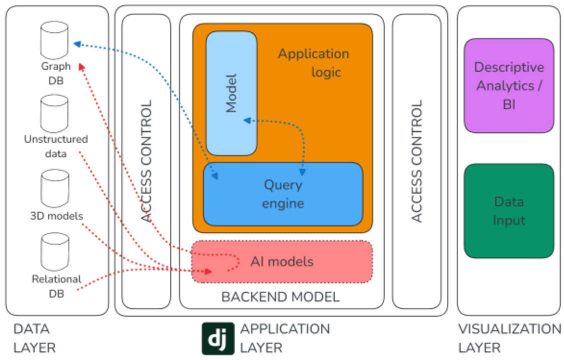

Figure 3: DTE System Architecture

The digital twinning capabilities are demanded to the application layer, where an integrated digital model is built, based on a multitude of heterogeneous data sources. They include virtual 3D representations (BIM models) of valuable assets, factual information across their lifecycle and contextual semantics, and their extraction and transformation are supported by AI models inferencing capabilities, as investigated in previous research. Aiming at interoperability, open data formats and schema (Pauwels et al., 2022) shall be considered for primary integration. Inside the application logic, modules taking care of the generation of visuals through the selection and query of pertinent data are built, also modelling data and schema constraints relevant to the single case study. Due to the mutable nature of real-world conditions, such as local regulations or organizational processes, logical and relational constraints are more efficiently defined at application level, rather than being too strictly declared at ontological level. Application layer modules trigger workflows as represented in Sequence Diagrams, performing domain integration and orchestrations tasks, leveraging the graph database constituting the backbone of the system. The visualization layer is the UI supporting different user groups throughout the entire asset lifecycle, contextualizing cross-domains data inside each specific visualization page and report.

A system development phase follows, guided by Domain-Driven Design (DDD) (Evans, 2003) and object-oriented approaches, which adopt Strategic Design to model complex domains and promote an event-driven architecture, incorporating domain events to trigger workflows. Moreover, the exploitation of domain events allows to effectively decouple various parts of the system, thus facilitating modularity, scalability and improved maintainability. The planning and prioritization of improvements steps, as the update of singular modules, instead of impacting the whole system at once, ensures resilient and efficient SAs.

Case Study

A pilot of the conceptualized system has been developed, adopting a Django framework, which enabled the transfer of domain knowledge into class modelling, while use-cases into views and forms, also tailoring user requirements into interactive yet simple web pages. To overcome the non-native integration of RDF in the adopted framework, instead of Django's Object-Relational Mapping (ORM), Python classes are used. Their definition in the application logic enables the bidirectional mapping and retrieval of data towards the graph database through a query engine (SPARQL endpoint). Backend data derive from a real-world situation, which is an historical building owned by the University of Turin and hosting administrative offices, namely "Palazzo degli Stemmi". Information content relevant to WM practices depicts building spaces, furniture, ICT assets and employees, whose details have been anonymized to not expose personal data. The database content has been transformed into an RDF-compliant graph, semantically aligning entities with modular ontologies, and imported in a graph store (i.e., Ontotext GraphDB). The resulting graph (*Figure 4*) successfully links employees to OUs, to assigned ICT Assets and to Workspaces, which are in turn mapped to the building spatial structure. The underlying data schema is based on a custom enterprise ontology (with the prefix *wmto:*), introducing organization-specific WM concepts on top of aligned well-established ontologies. It imports FM concepts from the Real Estate Core Ontology (https://w3id.org/rec#, with the prefix *rec:*) and the Building Topology Ontology (https://w3id.org/bot#, with the prefix *bot:*), as from The Organization Ontology (http://www.w3.org/ns/org#, with the prefix *org:*), the Schema.org Ontology (https://schema.org/, with the prefix *sdo:*) and the Friend-of-a-Friend Ontology (http://xmlns.com/foaf/0.1/, with the prefix *foaf:*) for HR management purposes.

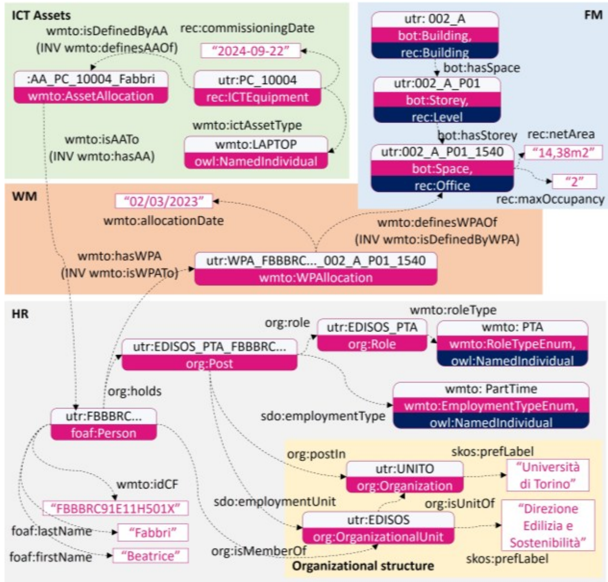

Figure 4: Graph visualization of Case Study data

The segmentation of domains involved is reflected in the design of the UI as well, where users can access dedicated sections, depending on their role. Each visualization satisfies functionalities stated in the stakeholder requirements, but also answer to UCs needs related to data schema, as it is built on top of semantically coherent SPARQL queries. Technical employees (see UC *"Load Data" Package*) can visualize existing information and insert new sets of data respectively from the HR, ICT and FM sections listed in the app menu. OU Managers only (see UC *Allocate Employee to Workspace*) are allowed to access the WM section, where they can first retrieve a list of employees filtered by the OU. The webpage dynamically enables the selection of the employee of interest, of which are shown personal details and (if any already assigned) the workspace he is allocated in. This page then enables the (re-)allocation procedure, sending them to the database and updating all visualizations reporting such information.

This activity mimics current managerial practices, where the OU Manager oversees teamwork evaluation and equipment requirements, as employees' personal needs, but can now access all relevant information from an integrated platform, performing informed decisions. Moreover, the interconnection of multi-domain professional competences through the system mirrors organizational interactions and technical procedures, motivating employees to engage in collaborative tasks.

An incremental implementation of the proposed DTE is envisioned, and the definition of a programmatic capability ladder (Altamiranda, 2024) could guide its execution: from integrated yet merely descriptive capabilities about the assets represented, to diagnostic and predictive capabilities, enabling the system to suggest optimization strategies based on conditions changes in the real-world counterpart, and further on with autonomous capabilities, if IoT equipment and intelligent control systems were to be added.

Discussion

The proposition of a DTE for WM aims at positively impacting how large organizations allocate office spaces, reducing the challenges posed by existing decisional practices. It does not only unify previously discontinuous knowledge silos, promoting informed decision-making, but also fosters proactive teamwork. The existence of well-established work procedures, related to employees' competences, values the responsibilities of the individual and reflects into better data management practices. This subsequently impacts the whole pipeline, since data quality is crucial for extracting meaningful insights. Inherently to the domain investigated, the proposed system enables OU Managers to act on individual spaces with an overview on the current situation of a whole floor or building, even in interdependence with needs of other OUs. Decision-makers are entitled to consider employee collaboration networks, as well as comfort levels related to space occupancy, having their choices impact workers' health and performance. Moreover, tracking not only the allocation of human capital to office spaces, but also that of physical assets, paves the way to solving other managerial concerns, such as those related to inventory and end-of-life of such objects.

Additionally, sociotechnical factors related to sector-specific regulations, risk management requirements, organizational policies and culture, play a steering role in understanding the fragmented nature of the investigated domain. While non-functional requirements aim to tackle regulatory and safety compliance, organizational culture factors are far more challenging. They deal with change resistance and with departmental data and knowledge silos, related to skill segmentation of employees, to long-established routines and to vendor-locked software use, requiring integration or migration towards the proposed system.

A SE approach, by revealing inefficiencies and bottlenecks in existing workflows, promotes the development of modular solutions for a scalable and flexible implementation within the organization SA. The proposed SA, through its application modules and structured visualization pages, facilitates contextualizing information while confining multi-domain complexity, also enabling data governance and exposing data for consumption in secure environments. The extension of the SA to other domains, through a SE methodology, aims to demonstrate that a scalable DTE is a feasible solution, allowing ongoing refinement of modules, adapting to changing organizational needs. The adoption of a DTE could, in future, support the optimization of all such organizational workflows, as AI algorithms powering KG-based CDTs enable the simulation of scenarios and their impact on process efficiency could be easily showed.

To ease the delimitation of application boundaries, the proposition of a DTE for WM here presented leveraged a SE approach, based on the analysis of UC scenarios. These latter made it dependent on the specific needs elicited and are intrinsically validated through the fulfilment of SPARQL queries, which regulate the retrieval of data populating the system visuals. This approach aims at being replicable for other large organizations dealing with WM practices, as well as being scalable and adaptable to additional intra-organizational domains, as per a System-of-Systems (SoS) concept. The prototype developed is validating its applicability and performance on a real organizational setting, but further iterative refinements are envisioned, relating on usability testing, to improve the UI and all implemented functions.

Future developments will face both organizational and technical challenges, aiming to fulfil all functional and non-functional requirements through software development. This primarily relates to dealing with the incorporation of heterogeneous data and their semantic alignment with domain knowledge, but also with security concerns and access management. The implemented visualizations dedicated to workspace allocation procedures currently enable informed but subjective decision-making, but potential improvements should consider the integration of dynamic multi-criteria optimization algorithms, suggesting suitable allocation scenarios. At the organizational level, challenges related to the strategic decision of DT implementation should focus on the adoption of a data-driven business model and on its impact in digital transformation. The single real-world case study will dictate the depth of detail and granularity the system should reach, resulting in trade-off evaluations between technological, organizational and financial costs. Moreover, outlining a phased adoption roadmap will address organizational cultural resistance, bridging sociotechnical barriers through modular architecture implementation.

Conclusions

The presented study contributes to the WM domain, both from an organizational and a technological perspective, by proposing a solution that addresses the inconsistent and time-consuming nature of traditional workspace management tasks. Provided that proper management of assets contributes to value creation in organizations, this study leverages the methods of SE to propose a DTE. Based on such principles, it attempts to offer a holistic approach to integrating multi-domain data and stakeholder perspectives into a unified platform, addressing the complex challenges of WM in large organizations. Starting from eliciting stakeholder requirements, up to the formalization of UCs depicting user interactions with system functionalities, and to the proposition of a SA, the rationale behind a WAMS is explained. It aims to streamline decision-making processes for OU Managers, enabling them to optimize workspace allocation and utilization, based on comprehensive information and insightful visualization reports. Referring to the SA and both functional and non-functional requirements outlined, a foundation for developing KG-based systems for AM through pilot implementation is set. While challenges and limitations exist, the WAMS serves as a catalyst for future research and development in digitized, holistic approaches based on SDTs in the built environment, also promoting a scalable adoption in other managerial domains.

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