

EFFICIENT COORDINATION OF TELECOMMUNICATIONS ROOMS
THROUGH PRE-DEFINED ONTOLOGIES IN BIM-BASED AIRPORT
PROJECTS

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THROUGH PRE-DEFINED ONTOLOGIES IN BIM-BASED AIRPORT
PROJECTS**

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ABSTRACT

EFFICIENT COORDINATION OF TELECOMMUNICATIONS ROOMS THROUGH PRE-DEFINED ONTOLOGIES IN BIM-BASED AIRPORT PROJECTS

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Studies researching how to prevent time and cost overruns in construction projects has laid the foundation for Building Information Modeling (BIM) systems, which are being actively employed in the construction industry. The success of the BIM systems in the industry is attributed to stakeholders creating planned three-dimensional (3D) models and preventing clashes on-site. However, as emphasized by the theoretical studies, the true success of the process is contingent upon the early commencement of accurate information sharing, a crucial aspect often overlooked in the industry.

In complex structures like airports, subject to numerous regulatory requirements (hospitals, educational buildings, consulates, etc.), the early initiation of inter-party information sharing is particularly vital in the coordination processes. If the regulatory compliance audits are delayed to later phases such as construction or on-site coordination, this can result in a need for revisions in the work of various disciplines. In the present Information Age, the coordination of telecommunication rooms in airport facilities, where data usage and storage are continuous necessities, holds a significant importance.

The aim of this study is to establish a framework that can be employed by designers, consultants, and relevant disciplines within contracting firms to ensure the initiation of the coordination for telecommunication rooms at airports during the early stages of a project. Initially, the necessity of conveying relevant information regarding the layout regulations of telecommunication rooms in early stages of airport projects has been discussed with industry representatives, and existing problems were identified through a literature review. Subsequently, an ontological approach has been proposed to solve or even mitigate the occurrence of identified problems, and the results have been analyzed.

Keywords: Airport Buildings, Information and Communication Technologies, Telecommunication Rooms, Roadmap

ÖZ

BİM TABANLI HAVALİMANI PROJELERİNDE ÖNCEDEN TANIMLANMIŞ ONTOLOJİLER İLE TELEKOMÜNİKASYON ODALARININ ETKİN KOORDİNASYONU

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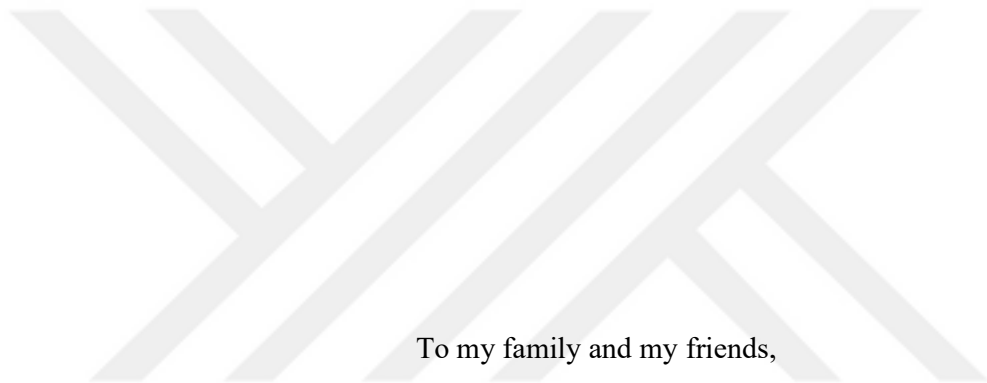
İnşaat projelerinde zaman ve maliyet kayıplarının önlenmesi için yapılan araştırmalar, yapı bilgi modelleme (YBM) sistemlerinin temelini oluşturmuştur ve sektörde aktif olarak kullanılmaktadır. Sektörde YBM sürecinin başarısı, tarafların planlanan zamanlarda üç boyutlu (3B) modeller oluşturmaya ve sahadaki çakışmaları engellemesine bağlanmıştır. Ancak teorik çalışmalarda da sıkça vurgulandığı gibi, sürecin esas başarısının doğru bilgi paylaşımının projenin erken aşamalarda başlaması gerekliliğine dayandığı sektörde göz ardı edilmektedir.

Havalimanları gibi bir dizi yönetmeliğe tabi olan karmaşık yapıların (hastaneler, eğitim binaları, konsolosluklar vb.) koordinasyon süreçlerinde, taraflar arası bilgi paylaşımının projenin erken dönemlerinde başlaması özellikle önemlidir. Yönetmelik uygunluk kontrollerinin uygulama projesi safhasına ya da saha koordinasyonuna bırakılması, birçok disiplinin çalışmalarında revizyonlara yol açabilir. Bilgi çağında yaşadığımız bu günlerde, veri kullanımı ve depolaması sürekli bir ihtiyaç olduğu havalimanı yapılarında telekomünikasyon odalarının koordinasyonu büyük önem taşımaktadır.

Bu çalışmanın amacı, havalimanlarındaki telekomünikasyon odalarının koordinasyon sürecinin projenin erken aşamalarında başlamasını sağlamak için

tasarımcılar, danışmanlar ve müteahhit firmaların ilgili disiplinleri arasında kullanılabilecek bir çerçeve oluşturmaktır. İlk olarak, havalimanı projelerinin erken dönemlerinde telekomünikasyon odalarının yerleşim kurallarının ilgili bilgilerin birimlere iletilmesi gerekliliği, sektör temsilcileri ile tartışılmış ve mevcut problemler literatür taramasıyla belirtilmiştir. Ardından tanımlanmış sorunların çözülmesi hatta önüne geçilmesi için ontolojik bir yöntem önerilmiştir. Önceden belirlenmiş bir aksiyon haritası ve yönetmeliklerden elde edilen bilgilere dayalı bir koordinasyon sürecinin, bir ontoloji haritası kullanılarak nasıl yürütülebileceği senaryosu incelenmiş ve sonuçlar analiz edilmiştir.

Anahtar Kelimeler: Havalimanı Binaları, Bilgi İletişim Teknolojileri,
Telekomünikasyon Odaları, Aksiyon Haritası



To my family and my friends,

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LIST OF ABBREVIATIONS

ABBREVIATIONS

AACI	Airport Association Council International
ABC	Automated Boarder Control
ADRM	Airport Development Reference Manual
AEC	Architecture, Engineering and Construction
AECOO	Architecture, Engineering, Construction, Owner, and Operation
BHS	Baggage Handling System
BICSI	Building Industry Consulting Service International
BIM	Building Information Modeling
BOT	Building Topology Ontology
CUSS	Common Use Self Service
IATA	International Air Transport Association
ICT	Information Communications Technology
ITA	Institute of Air Transport
MER	Main Equipment Room
NFPA	National Fire Protection Association
OWL	Web Ontology Language
RDF	Resource Description Framework
RFID	Radio Frequency Identification
SER	Secondary (Satellite) Equipment Room

SHGM	Directorate General of Civil Aviation
SSBD	Self Service Bag Drop
SSBG	Self Service Boarding Gate
SWRL	Semantic Web Rule Language
TIA	Telecommunications Industry Association
TR	Telecommunications Room
W3C	World Wide Web Consortium

CHAPTER 1

INTRODUCTION

This introductory chapter presents the background research that lead to the identification of the research problem. It is followed by the problem statement, the aim and objectives, the research procedure and disposition of the thesis.

1.1 Research Background

Today, airports are no longer simple passenger transit areas but rather landmarks of modernity, globalism, and connectivity. The rapid development and improvement of technology in the 20th century carried the airport industry to an unprecedented level, and architects have tried to put their most fascinating designs on stage for terminal buildings. However, the priority for the passengers have always been reaching their destination and leaving the airport as soon as possible, and this explains why project stakeholders and architects have worked so hard to integrate digital technologies into airport design. (Heathcote, 2014) As a result, airports turned into digital flexible transport hubs where architectural innovations merge with the demands of the digitalized era.

The rapid development followed by the increased number of passengers and this increment has caused tremendous traffic in airport operations. Therefore, airport operators have requested solutions from architects. Roughly, three typologies (linear, finger and satellite) of airport design have evolved during the changing and developing environment of the aviation industry. Additionally, airports became integral to economic and social development of governments that coined the “aerotropolis” term, which emphasizes the seamless and secure airport usage

integration with the city. (Kasarda & Lindsay, 2012) The intersection of technological developments and architectural solutions has revealed the advantages and disadvantages of the new era in aviation industry. Digitalization of airports has stepped in to solve the existing problems and to improve the contemporary processes. (Alici, 2023)

The expectations of travelers are shifting towards more sustainable, digitally enhanced, and customized flying experiences. IATA has published “New Aviation Ecosystem Roadmap” report in 2023 to underline the existing studies related to new innovative aircraft technologies (such as electric vertical takeoff and landing (eVTOL), electric short takeoff and landing (eSTOL) aircraft, supersonic jets, commercial space vehicles, and aircraft powered by alternative energy sources, etc.) to meet the passengers’ demands and give a timeline to aviation sector for adaptations in operations and airport infrastructures. Despite these aircraft advancements, the rigidity and non-adaptable environment of existing infrastructure have been highlighted and the necessity for a fundamental reevaluation of the entire aviation ecosystem has been underscored. (IATA, 2023) Integrating digital infrastructure into airport design is essential for accommodating these forthcoming technological advancements and adapting to future changes in aviation. (Alici, 2023)

Information and communications technology (ICT), which is the basis of the digital infrastructure, has stood as the keystone of business, finance, healthcare, education, agriculture, government, and transportation. The advantage of remote collaboration and seamless data access facilitated by ICT, have become the most important efficiency and progress of the digital age. (Ambegaonkar, n.d.) Because of the mandatory security and safety requirements at airports, ICT has stood out with its adaptive environment and serves airport crisis management and passenger welfare. In the future, airport architecture and ICT structure will need to evolve together to answer the requests, not only regarding the enlargement of the space but also related to the effectiveness of the area related to ICT with structured cabling.

Even if it steps up as a standardization method in the United States by major telecommunication operators, at the end ICT takes the key role for feasibility and it opens the way for continuous upgrades. (Senanayake & Senanayake, 2022) The deregulation of the US regarding cabling could be seen as a problem but 1984 has been a key milestone for searching a uniformity and interoperability. There is a shift from tenant-based to centralized cabling with the transformation to structured cabling.

ICT systems becoming foundational components of buildings with technological developments lead to related sub-systems needing particular attention. Especially, telecommunication rooms (TRs), where vertical structured cabling systems are distributed horizontally, could no longer be defined as simple IT rooms. A significant coordination process is required for TRs and there are several specifications such as TIA and BICSI to guide airport project teams and emphasize the importance of ICT systems. (BICSI, 2020)

Design coordination requires merging various fields and information from Architecture, Engineering and Construction (AEC) sectors to create cohesive designs. Especially in today's complex construction projects to eliminate traditional methods' disadvantages, Building Information Modeling (BIM) has introduced collaborative work environment for all parties simultaneously. (Jin & Li, 2023) As it is underlined by Mehrbod et al. (2019), BIM has offered several solutions related to the new challenges and opportunities in the construction industry and automated clash detection is one of them. However, telecommunication room coordination which could be defined as specific ICT room coordination, requires a qualified approach to solve the indicated design coordination problems. (Mehrbod et al., 2019) As discussed previously, airports have evolved because of the dynamic needs of users and operators, technological improvements and intended search for unique designs and therefore, ICT has to cover and answer all these requests with its multi-dimensional infrastructure.

The transition to unique and complicated designs has brought challenges which have been leading to conflicts and loss of resources at construction sites. While AEC industry has been struggling with these issues, the sector experts shifted their focus to leveraging know-hows captured from previous projects. (Qi & Costin, 2023) The shift from traditional 2D coordination to BIM systems could be given as evidence highlighting the search for a solution in the industry. As an example, Jin and Li (2023) have investigated a common working methodology by using both 2D computer-aided design (CAD) and BIM to answer the need of digital information gathering and reusing in the construction sector. On the other hand, in order to store and benefit from the process steps and expert knowledge, the sector needs to; (i) clearly define the issues, (ii) investigate the key factors contributing to the project delays and (iii) understand industry reflexes towards these problems, which again requires domain expertise. (Wetherill et al., 2002) Jia L. et al. (2023) have underlined that information management in traditional construction sector still rely on tacit and unlinked information in the vast ocean of standards. Therefore, an ontological approach for information modeling and management has been presented in their study. (Jia et al., 2023)

Harman (2017) has defined ontology as a “study of being” which deals with understanding the fundamental nature and characteristics of things, where other philosophers has argued that the concept of ontology coming from the combination of Greek words *ontos* and *logos* has been sufficient for explanation. Like Harman, Neches et al. (1991) defined ontology as the description of keywords and how they relate to each other in a specific area, and the rules for how these words and relationships are used to define what the words cover. The rapid improvement in advanced information technology and artificial intelligence, ontology has become crucial across various sectors for enabling the reuse and exchange of domain-specific knowledge. (Neches et al., 1991)

The term ontology has emerged as a multi-faceted solution in AEC sector to ease the complexity of the project coordination and prevent unintended delays in the construction projects. The role of ontologies in construction process has been

indicated as creating a common ground for interdisciplinary coordination with its structured vocabulary. (Costa & Lima, 2014) From aesthetic considerations of architects to functional and economic requirements of the stakeholders, ontologies have been used to manage the decision-making process. Several organizations are now trying to create a shared platform collecting valid and verified ontologies under one roof and to update them according to the industry needs when it is needed. (Rasmussen et al., 2020)

1.2 Problem Definition

For defining the problem of the study, the literature review and results of a survey which was conducted with the industry experts have been used. The literature has been reviewed to answer following questions:

- Why do airports have complex and unique designs, and how do other building systems adapt to these designs?
- What is the significance of Information Communication Technologies (ICT) systems and why does it have a crucial role for airports?
- What are the current challenges in BIM-based airport projects regarding ICT rooms coordination?

After gathering related studies from literature, to identify the current challenges of telecommunication rooms coordination in BIM-based airport projects, a survey was conducted with industry experts. As the survey outcomes indicate, in construction projects ICT has not been prioritized and this situation causes tremendous rework and delays.

1.3 Aim and Objective

The main goal of this study is to develop a pre-defined set of rules for TR coordination in BIM-based airport projects. This rule set is to define the constraints

for the telecommunication room and indicate a structured workflow between different disciplines and parties. There is no one correct way to define the relationship sequence between parties; therefore, in this study the defined structured framework is to be reviewed by industry experts. Following objectives have been identified to reach the main aim:

- Exploring the TR coordination rules and steps in current airport projects.
- Defining the strengths and weaknesses of the conventional coordination techniques in BIM-based airport projects.
- Developing a pre-defined ontology to accelerate and increase the efficiency of TR coordination in BIM-based airport projects.

1.4 Procedure

The procedure defined for this thesis paper begins with an extensive literature review pertinent to the research objectives. Critiquing literature will allow for defining current gaps and challenges, thereby facilitating the refinement of the objectives. Next, a survey involving industry experts within the aviation sector will be conducted. This effort aims to elucidate their current perceptions of information communication technologies and benefits of pre-defined rule sets for coordinating telecommunication rooms. Integrating insights from both the literature review and survey outcomes, a rule set governing communication and verification steps will be developed, mindful of spatial constraints stipulated by industry standards. Subsequently, the developed system will undergo rigorous testing by industry experts and research findings will be presented in the concluding discussion.

1.5 Disposition

The thesis comprises a total of five chapters, with this initial chapter dedicated to presenting the research background, defining the problem statement, outlining the aim and objectives, detailing the research methodology, and providing an overview of the thesis structure.

The second chapter provides an overview of the relevant literature, focusing on the digital transformation needs of airport architecture and the role of ICT in enhancing airport efficiency. It explores the advantages and challenges of current ICT coordination practices and emphasizes the critical importance of Telecommunications Rooms (TR) in structured ICT cabling, referencing relevant standards such as BISC and TIA. The discussion also covers the application of BIM in managing large-scale projects and concludes with an introduction to the development of ontologies in the construction sector, highlighting their potential for improving knowledge and process sharing.

In the third chapter, the survey results among industry practitioners are explored. It presents the findings from these surveys and discusses these results in relation to the comprehensive literature review on complex airport projects, highlighting the need for interdisciplinary coordination and structured decision-making frameworks. Insights from architects and engineers, collected through both quantitative and qualitative methods, are crucial for understanding the existing challenges in coordination techniques and identifying bottlenecks in the process.

In the fourth chapter, the development methodologies for the pre-defined rule set designed to enhance TR coordination in BIM-based airport projects are detailed. This chapter presents the ontology development methods that have been adapted for the construction industry. This approach underscores the study's aim to streamline and improve coordination processes effectively.

In the concluding chapter, the research findings are synthesized, summarizing the major contributions and the implications of the developed rule sets for

telecommunications room coordination in BIM-based airport projects. This chapter reflects on the research objectives, discussing how they were addressed throughout the thesis. Additionally, it highlights the limitations encountered during the study and proposes recommendations for future research, setting a path for further investigation and development in the field.



CHAPTER 2

LITERATURE REVIEW

The literature review presented in this chapter, discusses airport architecture and its digital transformation which emphasizes the importance of information communication technology (ICT) coordination in airport buildings. First, a brief explanation of terminology has been provided to show advantages and disadvantages of current ICT coordination processes for all project stakeholders. Next, the importance of the Telecommunications Rooms (TR) for the properly structured ICT cabling has been underlined and the rule sets which were defined by the related standards (BISCI and TDMM 14th Ed.) for the TR Rooms have been reviewed to understand the constraints for all parties. Afterwards, Building Information Modeling (BIM) has been presented as the latest and improving information modeling and managing tool for mega projects and the challenges caused by the BIM process have been discussed. Finally, the ontology development in the construction sector for effective knowledge and process sharing has been introduced with its future opportunities.

2.1 Airports and Digitalization

“Airport architecture is a conundrum: no matter how good it is, users want to leave as soon as possible.”

- Edwin Heathcote (Heathcote, 2014)

The speed of technological developments and improvements in the 20th century impacted the aviation industry. The rapid developments in caused air travel to surpass other alternative transportation methods (Edwards, 2005) and a need for

increasing number of airport buildings was born due to this evolution and growth in the industry. Like central stations for railways, airport terminals can be defined as “main buildings” where passenger traffic is controlled, and a pleasant experience is provided until passengers depart. In addition, because of the popularity that aviation gained, airport terminals are now perceived as landmarks. (Edwards, 2005)

2.1.1 Evolution of Airport Architecture

The increasing excitement for aviation could be perceived by many, and architects were not different. In his book “Naked Airports”, Gordon (2004) highlights that after developments in air transport, Walter Gropius mentioned architects should spend much more time designing the top views/perspectives of their buildings. Le Corbusier was also charmed by this brand-new technology, and he stated that this speed deserves a new approach for the design of cities, as shown in Figure 2.1. (Gordon, 2004) In 1933, Friedrich Dyrssen and Peter Averhoff designed one of the first airports in Europe. In this airport built in Hamburg, different functions have been located at different levels. Unlike today's airports, there is a dedicated level for non-travelling citizens with restaurants, cafes, and observation decks. (Gordon, 2004) These ideas constructed the definition of the airport not only as a building, but also as a cultural gateway and an urban area independent from its city. (Edwards, 2005)

The development in the aviation industry accelerated day by day after the mid-1950s. Several architectural layouts evolved to answer the growing capacity needs at the airports. (Ruggiero, 2020) Today, there are three main design concepts that are used for airports across the world according to the dedicated area and environmental factors. These are (i) linear design, (ii) finger design and (iii) satellite design. (Everything Aviation, 2020)

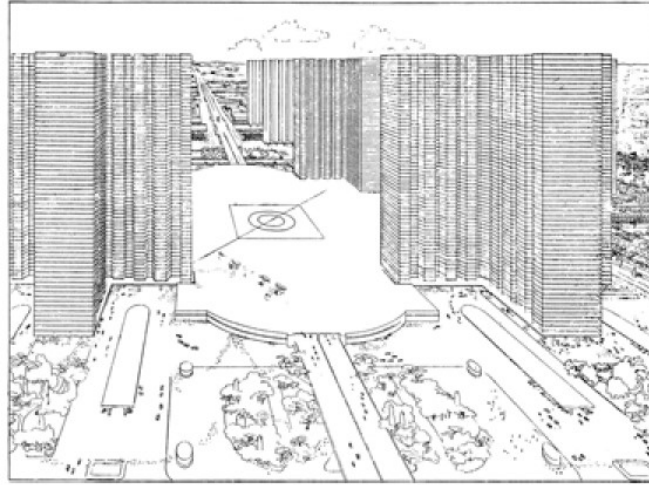


Figure 2.1 “A city made for speed is made for success.” 1922 (Gordon, 2004)

Peter Ruggiero (2020) who is the architect for redesigning New York’s LaGuardia Airport Terminal B, mentions that in the linear terminal buildings, airplanes directly park in front of the terminal like cars park in front of any building. Terminal building itself serves as a line between the airside and landside in the linear configuration and generally the building has one passenger processor area. (IATA, 2019) According to the site conditions, by the help of the linear geometry which can be straight or curved, the building could expand on both ends when necessary. Figure 2.2 shows Kansai Airport in Japan as an example airport with linear configuration. (Edwards, 2005) However, in linear configuration, the expansion might affect the passenger connection times and high passenger traffic might be observed at the main passenger processor. (SHGM, 2006) As it is recommended by IATA (2019) and presented in Table 2.1, the terminal design should follow the agreed Minimum Connecting Time (MCT) for the best practice. When expansion is necessary, linear configuration is duplicated closer to the apron to reach this level of service (LoS). This means that the main passenger service area must be relocated to the second building. A similar expansion occurred at Dallas Airport in the U.S. five times, causing major increase in operation and maintenance costs. (Everything Aviation, 2020)

Table 2.1 Best Practice Minimum Connecting Time (IATA, 2019)

	Domestic to Domestic	Domestic to International	International to Domestic	International to International
MCT	35-45 mins	35-45 mins	45-60 mins	45-60 mins



Figure 2.2 Linear configuration at Kansai Airport, Osaka, Japan. (Edwards, 2005)

Finger design configuration has one processor area for passengers and serves different piers which were connected perpendicular to the concourse. (IATA, 2019) Ruggiero (2020) described this design as multiple linear configurations connected to the centralized processor. (Figure 2.3) For finger design, there are three types of configurations: X-type, Y-type, and H-type. For all types, on larger scales, the main passenger processor area could include several semi-centralized processing areas that use the same arrival and departure concourse. This configuration is a more efficient concept for the passenger control and creates a more suitable environment for the operations of multiple airlines, however, there is a huge potential to create long walking distances for passengers (if flight connections could not be arranged properly) and generally could not provide a flexible environment for any expansion. (IATA, 2019)

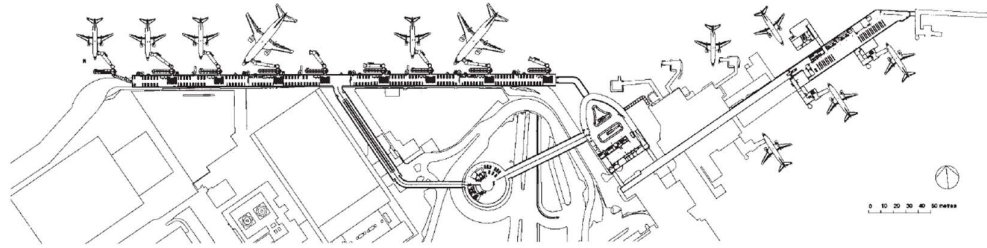


Figure 2.3 Finger configuration example from Heathrow Terminal 4, UK.
(Edwards, 2005)

In ADRM 11th Edition, satellite configuration is generally defined as a combination of finger and linear design. There is a main terminal building which encounters passengers from the landside and includes the main passenger processing area and there are remote satellites which are not directly integrated to the main terminal as they are in finger configuration. The connections between satellites, which are used as easy parking spots for airplanes, and the main building are provided with bridges above or below-ground links. In these connection bridges, sometimes travelers could be enough to expedite the passenger flow to reach the desired connecting time. On the other hand, in some cases, Automated People Mover (APM) systems were used for connections. (IATA, 2019) For instance, at Stansted Airport in London, there is a Track Transit System (TTS) from main terminal to satellites.

Overall, satellite design can be considered the most efficient configuration for airside operations and airplanes. Aircrafts can easily connect to satellites to take on/drop off the passengers and if needed, satellites can be differentiated as arrivals or departures for operations. Additionally, having a single connection area at the main terminal with landside facilitates passenger experience. (IATA, 2019) On the other hand, IATA acknowledges that during the peak hours, this single connection might create a bottleneck for all operations.

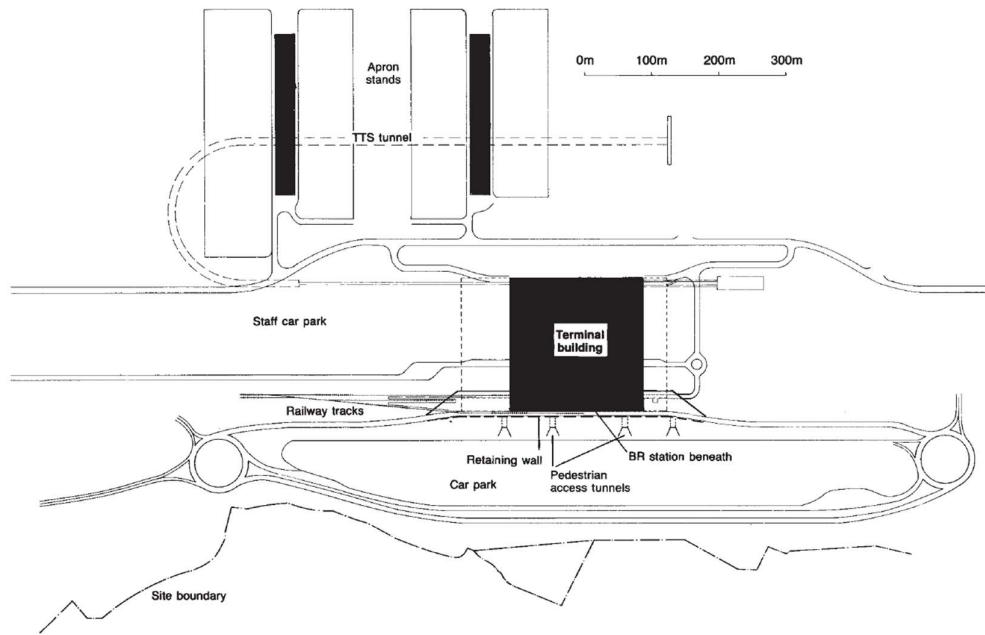


Figure 2.4 Satellite configuration sample from Stansted Airport, UK. (Edwards, 2005)

2.1.2 Evolution of Airport Operations

Linear, finger and satellite configurations have been evolved throughout the history of the airport architecture to answer the passengers' and operators' needs constantly. Simultaneously, due to the increasing number of travelers, operation definitions have been enlarged or evolved. Fattah et al. (2009) defines the early airport terminal buildings as simple train stations where passengers have been simply directed to their aircraft. The ticketing and check-in process, general waiting lounges and baggage carrying service were the main operations which appear to be the primitive versions of their counterparts in today's modern airports. (Fattah et al., 2009) On the other side, flying gets in front of the other transportation methods day by day and the architects, engineers and clients have wanted to explore unique and challenging designs to reflect their cities' culture, knowledge, and capability to rest of the world. (Edwards, 2005) Furthermore, there has been increasing variety of design parameters such as requested aircraft and passenger types, aimed traffic load, expected

passenger services, and demanded security concerns. (Shevtsov, 2022) For these reasons, airport operations have reached their current diversity and complexity.

The airport has not been limited to the terminal building. Airport design consists of five subpackages; terminal building(s) and carparks, runways and taxi ways, air traffic control facility, buildings for aircraft maintenance and fuel warehouses according to Edwards (2005). On the other hand, Kovynov and Mikut divide airport operations like airport, air traffic control, airline, ground handling agent and police activities as indicated in Figure 2.5.

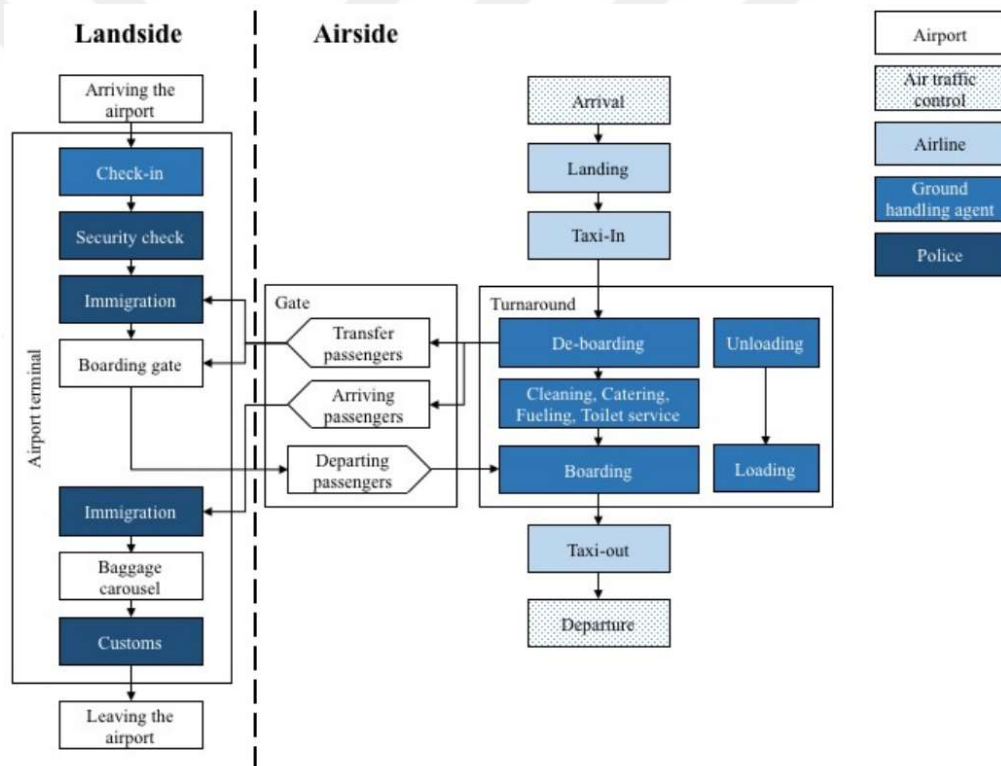


Figure 2.5 Airport operations diagram. (Kovynov & Mikut, 2018)

These divisions are unique for the airport projects to reach a properly working airport, the design functionality should be controlled and regulated by third parties. Three common control organizations could be given as examples for these, which are named as International Air Transport Association (IATA), Airport Association Council International (AACI) and Institute of Air Transport (ITA). (Edwards, 2005)

According to Shevtsov (2022), while dealing with airport design, architecture, engineering, and safety decisions must play a significant role to reach the efficient comfort and safety levels for passengers and these delegated organizations have created some roadmaps for designers, engineers and for clients, and their main aim is to develop strategies for the aviation industry. (IATA, 2018)

Edwards (2005) has summarized the needs of airport grow under five topics:

- *More aircraft with greater carrying capacity are needed.*
- *Airspace and traffic control facilities need to expand.*
- *New and enlarged runways are needed.*
- *Passenger facilities need to expand, especially terminals.*
- *New and more efficient means of reaching the airport are needed.*

These five points require revisions for all five subpackages which include specific and complicated operations, however due to the scope of this study, only terminal building operations are to be indicated.

The operations in terminal building for departure passengers have been summarized in SHGM (2006) as:

1. Controlled entrance (according to local codes if it is necessary) to the terminal building,
2. Taking their boarding passes from check-in desks and leaving their luggage if they have any,
3. Passing through security control zone (according to local codes the sequence of activities varies, this might be after passport control)
4. If it is an international flight, passing through passport control booths,
5. Reaching assigned boarding gate to board on plane.

For arrival passengers, operations have been indicated as:

1. Deboarding from plane
2. If it is an international flight, passing through passport control booths,
3. Collecting their luggage from baggage reclaim hall,

4. Leaving the terminal building.

The main components of the terminal buildings, including passenger transactions, are explained below.

Check-in Area: The welcoming area for the departure passengers where they are directed to check-in counters to check-in themselves and their luggage. The design of this area should allow passengers to recognize the desks easily. The size of the area depends on the number of passengers. (SHGM, 2006) In the latest IATA's Level of Service (LoS) Concept (Figure 2.6), which was published in 2022, the optimum check-in process time at counters has been given between 10-20 minutes and optimum space for passenger has been indicated as 1.3 to 1.8 sqm.

Security Areas: These are the areas where arrival/departure passengers and their carry-on items undergo thorough screening for prohibited items by using metal detectors, X-ray machines, and body scanners. These areas are to be located after check-in area for departure passengers and passport control area for arrival passengers. (IATA, 2019) The optimum security passing time per passenger has been given as 5-10 minutes and the area required per passenger has been suggested as 1 to 1.2 sqm. (IATA, 2022b)

Passport Control: For international flights, passengers' identities, and their legal permissions to enter or exit the country have been checked in these areas. These areas also define the airside-landside boundary for passengers. (IATA, 2019) In IATA's LoS infographic, the optimum time for passport control at the emigration desk has been given as 5-10 minutes and the area per passenger has been suggested as 1 to 1.2 sqm.

Boarding Gates: In these dedicated areas, passengers wait before their flights. These spaces are crucial for organizing the boarding process and ensuring passengers board their aircraft efficiently and safely. The optimum seating space per passenger has been given as 1.8 to 2.2 sqm and standing space 1.2 to 1.5 sqm. While waiting for

their aircraft, fifty to seventy percent of the passengers would be seated. (IATA, 2022b)

Baggage Claim Area: This is a section for arrival passengers where they retrieve their checked luggage after landing. This area has been located at the landside after the passport control and security areas. IATA (2022) highlighted that passengers expect to claim their baggage in a timely manner. Therefore, for narrow and wide body aircraft, IATA suggested 0-15 and 0-25 minutes from first delivery to last delivery on belt. The optimum space per passenger has been indicated as 1.5 to 1.7 sqm. (IATA, 2022b)

Customs Control: This is a crucial area where passengers and their belongings are inspected to ensure they comply with the country's laws regarding the importation of goods. This area is usually located after the baggage claim section and before the airport exit. IATA recommends that the optimum process time per passenger should be 1-5 minutes and the area per passenger should be 1.3 to 1.8 sqm. (IATA, 2022b)

These are the main operations in airports, and as is underlined in literature review previously, increasing number of passengers causes operational workload and longer waiting times which creates dissatisfaction for travelers. For this reason, airports have to expand to create bigger spaces or enhance their operation management to meet the expectations. The digitalization of airports has stepped in as a solution to improve the airport operations. (Alici, 2023)



Figure 2.6 Optimum Level of Service in terminal buildings. (IATA, 2022b)

2.1.3 Evolution of Airport Digitalization

Growing operation needs followed by the digital transformation in the sector and again airport design requires an adaptation. (Alıcı, 2023) Previously, there were two generations of airport design which were driven by increasing passenger needs, additional operational requests and evolving economical profit ways from airport project. With the third generation, now airports changing into transportation hubs which also include large scale railway or any other transportation system to have a link directly to the city and now the commercial areas have become a must in the complex. (Edwards, 2005) These additional interrelated needs also required to be a part of digitalization in aviation sector to enhance customer satisfaction. Furthermore, after Covid-19, airports faced with accelerated digital transformation scenarios. (Alıcı, 2023)

The operational needs for aviation have brought the term of airport to our lives and the airport architecture have constantly mutated to answer the operational

innovations, then today's airports have taken the stage with their huge economic potentials for passengers, governments, and operators. (Airports Council International, 2017) However, as it could be observed in other fields, this digitalization transformation has not initiated only for answering passengers' needs or implying operators' requests. In 2008, aviation industry has been affected by the global financial crisis as well because of the unstable fuel prices and demand decrease. (Fattah et al., 2009) Fattah et al. (2009) refers to IATA's predictions for decrease in passenger and cargo traffic in their report to underline the huge impact for the sector. At that critical point, the aviation sector needed to figure out a solution to get out of this turbulent atmosphere.

Prior to discussing today's digitalized airports (or on their way to digital transformation), according to Fattah et al. (2009) there are two airport generations. The first one has been only dealing with safe and efficient aircraft operations with elementary passenger services. The business model of these kind of airports has been seem similar with landlords, there has been no active services regarding with technology or operations from the building itself. Each business operator will use the building with their own technological perspective and therefore they need to make serious revisions to the rented area. (Fattah et al., 2009) The second one named as "agile airports", and they are using centralized and shared services for business units. This perspective creates a suitable environment for using same up-to-date technology and enables easy settlement for tenants; and the airport infrastructure has been adapted accordingly.

While leveraging from the economic benefits of the evolving airport buildings, the trust for air travel security had been shaken by terrorist attack on 11th September 2001. Due to many current terminals being built before terrorism emerged as a significant concern, there has been a recent focus on enhancing security measures. This has led to quick fixes that make things safer but have not always been well-planned or connected. (Edwards, 2005) In order to rebuild the diminishing trust and prevent terrorist incidents, security measures in new generation airports have become one of the major issues that change the airport infrastructure. Security precautions at

airports were significantly heightened. Metal detectors, X-ray machines, and later, body scanners became more commonly used. Additionally, more detailed inspections of passengers and their baggage were implemented. (Gordon, 2004)

The third generation is today's airports, which can be also named as "smart airports" by the industry. This naming is not only coming from using the latest technology, but this is also directly related with carrying the business in digital world itself. (Airports Council International, 2017) It utilizes digital technologies like indoor geolocation, passenger identity management, flow management, analyzing data, and the Internet of Things (IoT) to improve operations. Additionally, it focuses on securing these digital technologies against cyber threats to ensure that all systems function correctly. (Airports Council International, 2017) However, IATA (2018) highlighted that, digitalization also raises concerns, including an increased likelihood of cyber-terrorism and espionage. To seize these opportunities, it will be essential to navigate the challenges between safeguarding data privacy and meeting surveillance demands, requiring a reevaluation of the interactions among individuals, corporations, and governmental bodies. However, it has to be noted that there is a request from some governments for open passenger data sharing for security. (IATA, 2018) These two factors, data and geopolitics, have been taken as main drivers by IATA to discuss the possible scenarios for the aviation sector in "Future of the Airline Industry 2035".

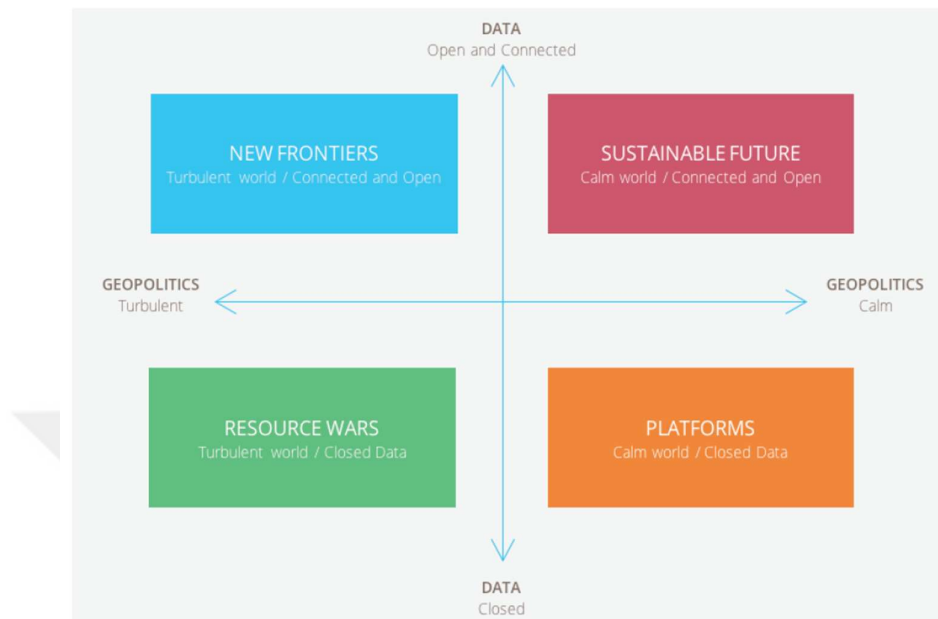


Figure 2.7 Four different scenarios according to Data and Geopolitics statuses (IATA, 2018)

Infectious diseases and pandemics also cause a turbulent atmosphere in geopolitics like terrorism and cyber-crime. In the 1960s, it was believed that many infectious diseases had been controlled, but the appearance of new viruses like HIV, SARS, and Zika reminded the world that health safety has to be considered as main parameter for airport infrastructure. (IATA, 2018) After the Covid-19 pandemic in 2019, to not to lose charm of the airports, aviation sector has pushed the digital transformation. This attitude has two main reasons. Firstly, during the pandemic, passenger travel had been restricted except for urgent flights. On the other hand, the aviation sector is faced with huge, unexpected cargo flight traffic with a limited employee and higher fuel prices. Therefore, it has been noticed that digitalization of the business itself will be beneficial for the future works. (IATA, 2022a) Secondly, after the pandemic, to recover the economic loss caused by decrease in the number of passengers, the airline industry has to provide a healthy, safe and efficient environment for their customers and employees. (Airports Council International, 2017) The pandemic has reminded the sector that the effective crisis management is

crucial for the aviation sector, and the digital transformation could provide the required flexibility to sector in challenging situations. (Kurnaz & Žilinskienė, 2022)

Third generation airports have not only used digitalization to prevent terror attacks or to respond pandemics with adaptable solutions. Edwards (2005) highlights that, since the early 1900s, the economic potential of the aviation sector has increasingly been recognized. Following the success of the first powered flight, the possibilities offered by air transport of people and goods have become evident. The advantages of speed, access, and efficiency provided by air travel significantly contributed to the expansion of intercontinental trade and communication during this period. Governments and the business community began to acknowledge the impact of aviation on economic growth of city/country, international trade, and tourism. As the 20th century progressed, the aviation sector assumed a central role in the global economy, acting as a catalyst for socio-economic transformations worldwide. To emphasize this centered position of airports, John Kasarda and Greg Lindsay have introduced the concept of “Aerotropolis”, which is used for describing the cities and business centers that have been developed around major airports. The word was first used by Nicholas DeSantis in 1939 for a drawing which represents an airport at the top of the skyscraper. However, Kasarda and Lindsay popularized this term to emphasize the importance of airports and for global connectivity and placing the airport in the center of the city has been suggested to facilitate global commerce and trade. (Kasarda & Lindsay, 2012) Before this concept was named, this development has been observed in some airports, such as Schiphol Airport in Amsterdam, Dallas/Fort Worth Airport in USA, and Dubai Airport. Bolat (2020) has defined seven main parameters to identify aerotropolis airports: (Bolat & Durmaz, 2020)

- **Customized Architectural Design:** includes luxury retails and food & beverage areas, natural resting areas, architectural design according to cultural values, dedicated areas for business gatherings, artistic & cultural activities, private lounges, and social activity areas.
- **Smart Technologies:** using the latest technology for transportation from city to airport and for aviation systems which could fasten the passenger process

time such as Common Use Self Service (CUSS) Kiosks (known as Self Check-in Kiosks), Self Service Bag Drop (SSBD), Automated Boarder Control (ABC) Gates, Self Service Boarding Gates (SSBG), etc.

- **Collaborative Working:** efficient interaction between stakeholders, organizational framework of the airport and management, long-term strategies and goals, diplomatic relationships.
- **Economic and Social Improvement:** achieving desired productivity with minimum cost by the help of closeness to the city, economic growth by bringing production, logistics and travel together, continuous incomes related to aviation and non-aviation, intertwining of trade and tourism.
- **Transportation:** Multi-modal transportation network between the airport and the city, global destination network breadth.
- **Environmentally Friendly:** Designs which increase the use of natural resources, having green areas in and around the airport, environmentally friendly transportation, and production (noise, emissions, electricity, etc.)
- **Sustainability:** All features within the scope of the aerotropolis need to be sustainable.

In these defined parameters for aerotropolis by Bolat and Durmaz, digitalization of the airport is a necessity for the use of smart technologies which has been defined as a base for data collection and usage by leveraging from internet of things (IoT) in several building types, for example, smart cities, smart buildings, smart factories, etc. Fattah et al. (2009) has identified smart airports as ecosystems which consists of a unified digital grid that allows high-speed data exchange and leverage from cutting-edge technologies to enhance their sense-analyze-respond capabilities. This digital grid (infrastructure) acts as the airport's central nervous system, enabling real-time information sharing, collaborative operations across different sectors, and comprehensive process integration, which increases operational efficiency, security, and passenger services. Moreover, smart airports elevate the passenger experience by offering personalized services through the seamless exchange of data, while

fostering broad integration across airlines, retailers, and other partners, generating widespread benefits throughout the value chain. (Fattah et al., 2009)

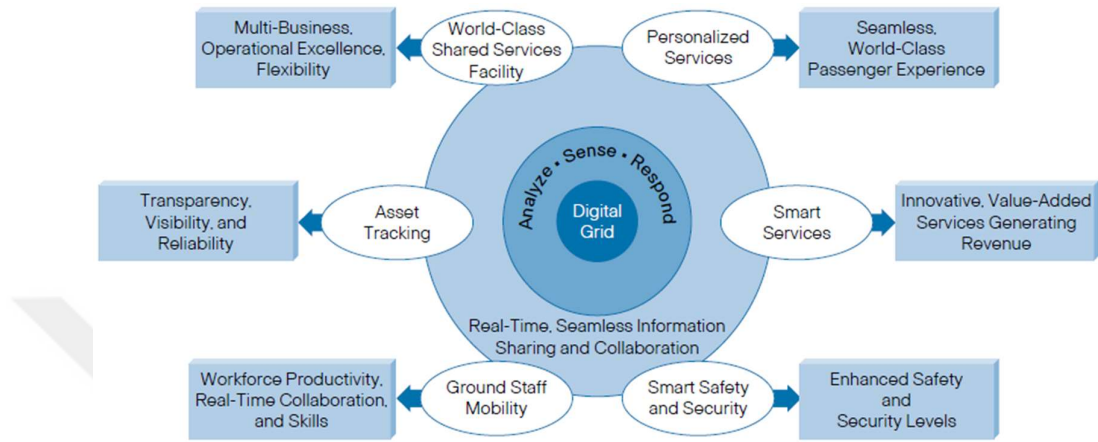


Figure 2.8 Smart Airport Components (Fattah et al., 2009)

As it is mentioned by Edwards (2005), there have been taxiways, apron facilities or warehouses for aircraft maintenance in airport complex and as Bolat and Durmaz (2020) have mentioned, smart airports include a lot of systems which create a comfortable travel experience for passengers and enable a secured landside-airside crossing for operators and governments. However, due to the scope of this study, only the smart technologies for passenger operations in terminal buildings are to be presented as examples for digital evolution in airports. As above-mentioned, (i) to deal with growing passenger volumes, (ii) enhance security needs, (iii) catch technological advancements, (iv) improve passenger experience, (v) take care of health and safety concerns, (vi) enhance the operational efficiency and (vii) increase globalization and internal collaboration, “single token journey” concept has emerged as a solution. (Challis, 2017) This concept has offered a pathway to more secure, efficient, and pleasant air travel in an increasingly connected and mobile world.



Figure 2.9 Smart airport systems for single token journey approach. (Challis, 2017)

The single token journey elements generally known as Self-Service Technologies (SST) devices and e-Gates which have been used directly by passengers without communicating with a service provider. (Challis, 2017) For check-in process, common use self-service kiosks (CUSS) and self-service bag drops (SSBD); for security solutions, automated border controls (ABC) and self-service boarding gates (SSBG) could be given as examples for SST's and e-Gates respectively.

Some of the main components of single token journey concepts are explained below.

Common Use Self-Service (CUSS) Check-in Kiosks: Self-service check-in kiosks are computer terminals that eliminate the need for ground staff for passenger check-ins, like ATM machines. (Fattah et al., 2009) Previously, airlines used exclusive kiosks for their passengers; however, today's kiosks serve for multiple airlines' check-in applications. By utilizing CUSS kiosks, airports benefit from efficient use of limited space, airlines eliminate capital investment by purchasing these services directly from ground handling agencies, ground handling agencies reduce operational costs by employing fewer ground staff for passenger check-in, and

passengers save time because they no longer need to search for airline-specific kiosks and can use any available kiosk. (Koroniotis et al., 2020) In Figure 2.10, a sample image for CUSS kiosk has been indicated with and without hand luggage scale option.

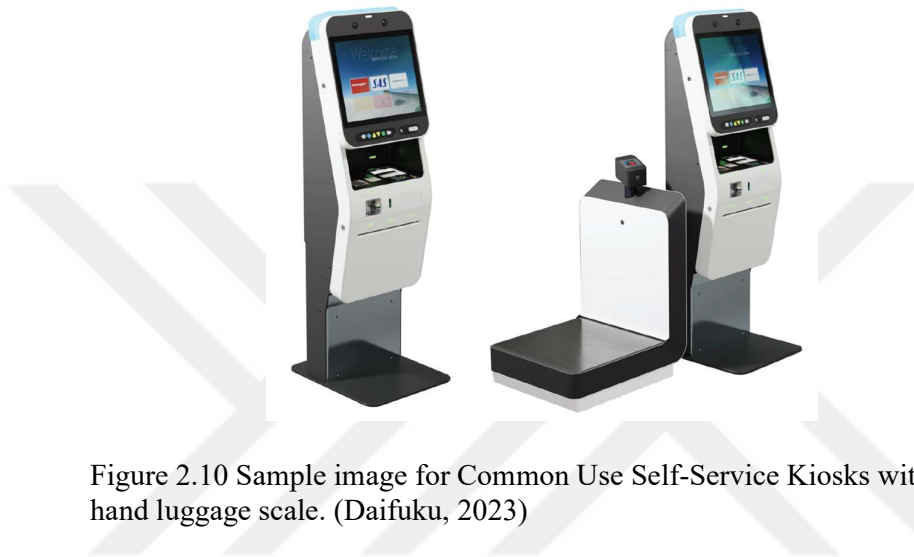


Figure 2.10 Sample image for Common Use Self-Service Kiosks with and without hand luggage scale. (Daifuku, 2023)

Self-Service Bag Drops (SSBD): Self-service bag drops offer a more efficient and user-friendly way to check in luggage. These systems allow passengers to bypass traditional check-in counters and drop off their baggage at automated stations, following simple instructions displayed on screens. The process involves passengers scanning their boarding pass, attaching the printed tag (RFID) to their luggage, and then placing it on a conveyor belt, where it's automatically sorted and sent to the aircraft. (Koroniotis et al., 2020) This innovation not only reduces wait times and congestion at check-in areas but also empowers passengers by giving them control over their check-in process. As it has been indicated in IATA's LoS infographic (2022), passenger's check-in time with luggage decreases to 1-7 minutes from 10-20 minutes which is the targeted time interval for conventional process.



Figure 2.11 Sample image for Self-Service Bag Drop. (Daifuku, 2023)

Self-Service Boarding Gates (SSBG): These automated gates allow passengers to board their flights by simply scanning their boarding passes or mobile devices, without the need for manual checks by airline staff. This technology reduces queues and waiting times for the passengers. Additionally, self-service boarding gates offer added security features, such as biometric verification methods including facial recognition or fingerprint scanning, to ensure that the person boarding the flight matches the identity of the ticket holder. (Challis, 2017)



Figure 2.12 Sample image for SSBG and real-life photo from Hamburg Airport. (Gunnebo, 2017)

Automated Boarder Control (ABC) Gates: These gates utilize advanced technology, including biometric verification such as facial recognition, iris scanning, and fingerprint identification, to expedite the border crossing procedure for travelers.

Upon arrival or departure, passengers can bypass traditional manned checkpoints by scanning their travel documents and undergoing biometric checks at these automated stations. This not only significantly reduces processing times, easing congestion at border control areas, but also enhances security by ensuring a highly accurate match between the passengers and their travel documents. (Challis, 2017) As it has been indicated in IATA's LoS infographic (2022), passenger's passport control time decreases to 1-5 minutes from 5-10 minutes which is the targeted time interval for manual border passing process.

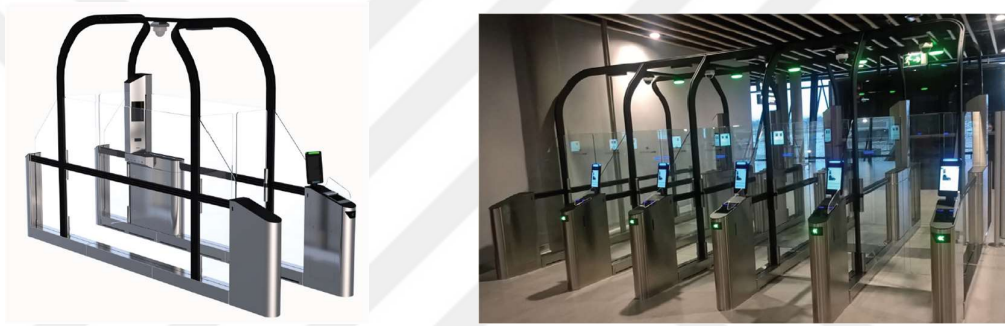


Figure 2.13 Sample image for ABC Gate and real-life photo from Lyon Airport. (Gunnebo, 2017)

These self-service kiosks and e-gates constitute a small portion of the single token journey approach, but they are the primary data collection points from passengers to airport operation systems. The communication between these devices and the data infrastructure (digital grid) is crucial to enable real-time data exchange through airport processes. To sum up, airports need to install these devices initially to reach the single token journey approach. (Fattah et al., 2009)

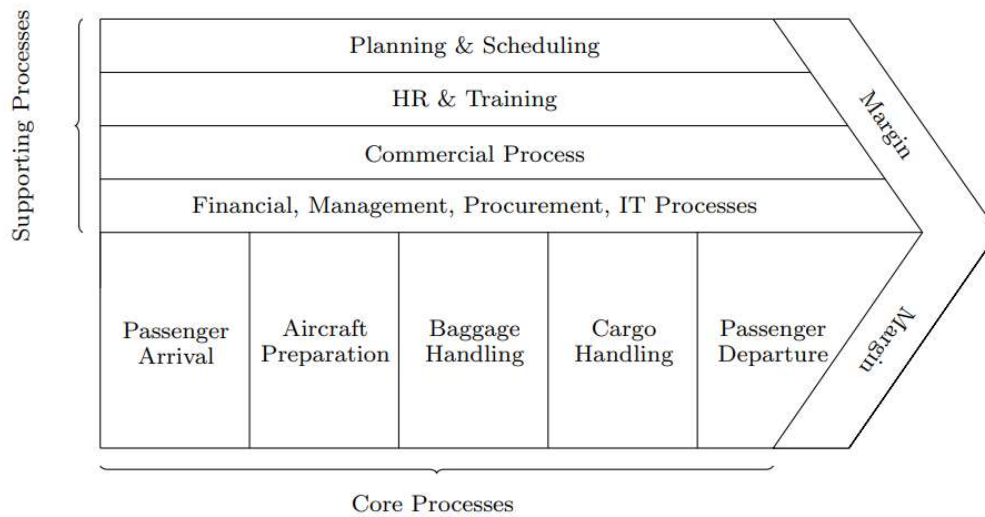


Figure 2.14 Ground Handling Operations Value Chain. (Kovynyov & Mikut, 2018)

While our study has primarily concentrated on passenger operations, it's important to note that airports manage a variety of other complex operations. How ICT systems fit into the broader airport operation framework is illustrated by the value chain model in Figure 2.14. This model clearly delineates the critical support and core processes necessary for airport management, ranging from passenger handling to cargo management, all supported by functions like HR, financial management, and notably, IT processes. This sets the stage for a deeper investigation into the integral role of ICT systems in enhancing operational efficiency and adapting to digital advancements within airports. By examining the ICT role within this framework, the thesis aims to uncover how technological integration can improve various airport operations, thus addressing the challenges of digital transformation in modern airports.

2.2 Information Communications Technology in Airports

ICT infrastructure plays a crucial role in today's world. In business, economy and finance, healthcare, education, agriculture, government and defense and various transportation systems, benefits of remote collaboration and seamless data access

have been utilized. (Ambegaonkar, n.d.) From the first generation of airports, safety and security of the passengers and operators is the most important topic for airport management, and Information Communications Technology (ICT) is the key system for airport demands. (Sahic & Cinac, 2022) The ICT framework is not only related to passenger monitoring but also used for optimizing flight schedules or finding an answer in a limited time for a flight crisis. Previously, airports answered the capacity increase with the expansion of the terminal buildings or with the use of satellite configuration, however for the ICT framework, expansion is not directly a solution because according to the experts' calculations the structured cabling has been provided. Therefore, this framework should be adaptable for possible updates to catch the improvements in the sector. (Kalakou et al., 2015)

Structured cabling has been first introduced as a standardization method for cables that are used for telecommunication systems by operators like AT&T and Bell. (Senanayake & Senanayake, 2022) These two companies are the major companies in the USA and generally dominated the industry with these standards. Then, the USA deregulated the telecommunication industry in 1984 to create a competitive environment for other small-scale companies. However, this deregulation meant for chaos for the industry, there would not be any common rules and regulations, each vendor could use their own systems and eventually this means that interoperability is not possible for different companies in this quickly growing sector. (FOSCO, 2012) After deregulation in 1984, a non-profit organization named as Building Industry Consulting Service International (BICSI) have provided support for AT&T services. (BICSI, 2020)

Before the 1990s, because cabling systems have been used as vendor specific, this creates obstacles during change of tenants. When there is a system upgrade, it requires renovation of cabling infrastructure and causes lots of rework. (FOSCO, 2012) Furthermore, these revisions and possible additions cause change or adaptations in major cabling plants. In 1991, Telecommunications Industry Association (TIA) published the first edition of "Commercial Building Telecommunications Cabling Standard" as standards for structural cabling.

Both in BICSI and TIA, structured cabling systems have been divided into 6 subsystems. In Figure 2.15, these systems have been indicated in the diagram and then briefly explained respectively.

1. Horizontal cabling
2. Backbone cabling (Vertical cabling)
3. Work area
4. Telecommunication Rooms and Enclosures
5. Equipment Rooms
6. Entrance Facility (Building Entrance)

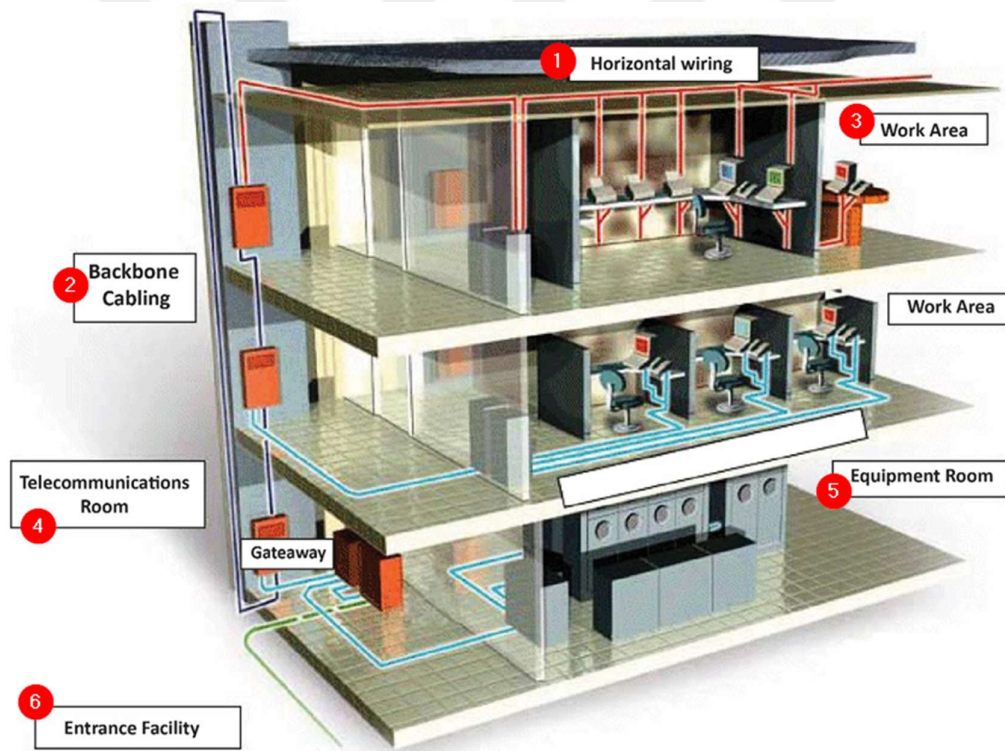


Figure 2.15 Six Subsystems of a Structured Cabling System ((FOSCO, 2012)

Horizontal cabling: This part of the cabling provides the horizontal connection from telecommunication rooms (TRs) to end points (telecommunication outlets-TOs). (BICSI, 2017)

Backbone cabling (Vertical cabling): This part of the cabling provides the connection between floors from entrance facilities or equipment rooms to TRs. These pathways are designed for including main and high-volume optical fiber cabling. (BICSI, 2017)

Work area: This area begins from the outside of the TRs, and it includes TOs on the walls which allows end-users to connect the structured cabling at the building. (BICSI, 2017)

Telecommunication Rooms (TRs) and Enclosures: These rooms are located inside the building to accommodate the cross-connects and patch panels. The vertical cabling feeds these rooms, and the horizontal cabling starts from there to rest of the floor. Therefore, these rooms can also be expressed as floor distributors. (BICSI, 2017)

Equipment Rooms: These areas are the main centralized areas with a specialized environment which includes telecommunications equipment. (BICSI, 2017)

Entrance Facility (Building Entrance): This area is the entrance space to a building for network cabling. In small buildings it is also named as entrance point (EP). (TIA, 2012)

2.2.1 The Role and Importance of Telecommunication Rooms

Telecommunications space is defined in BICSI as a generic name for all dedicated rooms (TR, ER or EF) where telecommunications equipment types included or separate rack cabinets in a room which is also serve to other functions. (BICSI, 2017) In these rack cabinets, cabling panels, telephone systems, UPS (uninterruptible power supply) systems, LAN (local area network) equipment and other types of data storage system cables included. These spaces differentiate in large scale projects such as Main Equipment Room (MER), Secondary (Satellite) Equipment Room (SER) and Distribution Equipment Room (DER). (Hoogenraad, 2019) In TIA-569-

C, these rooms mentioned as Distributor C, Distributor B and Distributor A respectively. This relationship has been illustrated in Figure 2.16.

- 1. Main Equipment Room (MER):** This room is the main location for the rack cabinets which includes all data cables inside. All cables (fiber optic or copper), which are coming from entrance facility, are to be distributed to optional secondary equipment rooms (SERs) or telecommunication rooms (TRs) or distribution equipment rooms (DERs). (TIA, 2012)
- 2. Secondary Equipment Room (SER):** This room is optional, and the requirement has been defined according to the project function and size. SER rooms have similar functions with MER, the only difference is, they could be located closer to their dedicated department or tenant. (Hoogenraad, 2019)
- 3. Distribution Equipment Room (DER):** According to the function of the building, there will be a single cabinet without any required cooling units, and this is named DER. The backbone of the cabinet has been directly connected to MER or SER. (Hoogenraad, 2019) According to TIA and BICSI, in commercial areas the cabling system will be finalized again with a closed space as telecommunication room (TR), to provide a controlled access to these rooms.

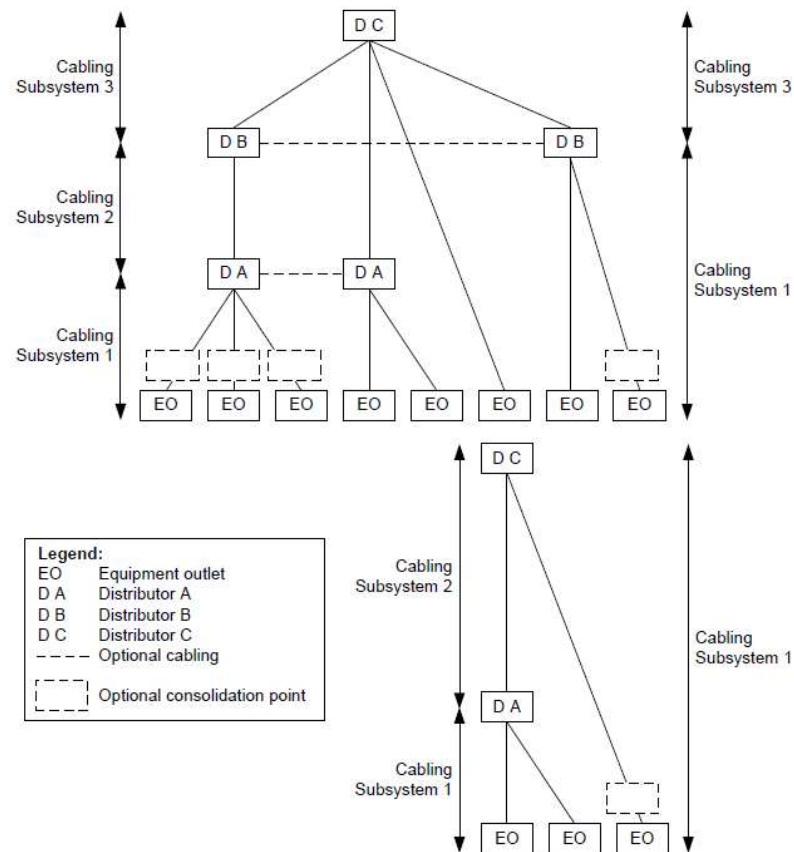


Figure 2.16 Cabling System Diagram (TIA, 2012)

The importance of the design and coordination of TR Rooms is not limited to airports. Structured cabling systems have also been preferred in healthcare industry, campuses for education, commercial buildings, government bodies, industrial automation, and data centers. (NCS, 2020) Therefore, a lot of institutes have their own guidelines according to the recommendations in BICSI TDMM and TIA's latest editions like UNINETT (2013) with higher education sector of Norway, Central Washington University (2005) and US. General Services Administration (2016) for governmental buildings. (Nygaard, 2013) (CWU, 2005) (GSA IT, 2016) TIA and BICSI provides best practice guidelines for the industry, however for each project an expert firm or consultant from the ICT sector should define the needs of the

building and should share this information with the architect in the preliminary design phase. (TIA, 2012)

As indicated in previous headings by Sahic (2022), in airport operations, data security and rapid transformation have crucial roles. Real-time monitoring of the operations and giving quick responses for potential problems requires a strong network system – like the nervous system in human beings. (Hatcher, 2016) Therefore, the proper coordination of the telecommunications rooms (MER, SER and TR) according to the specifications like BICSI and TIA, and specialized guidelines should be maintained prior to the opening of the airport building and this coordination should be initiated at the preliminary architectural design phase of the airport. (TIA, 2012)

2.2.2 Design Requirements of TR Rooms in Airport Projects

According to BICSI and TIA, there are some recommendations regarding the circulation space inside the telecommunications room and this differs according to their size. Additionally, for the rooms mechanical and electrical needs have been differentiating according to the type of the room (MER, SER or TR). (BICSI, 2020) For telecommunications rooms (or as it named as distributor room in TIA) have some common recommended parameters for its security, location, access, pathways, design (architectural and environmental), fire protection, water infiltration, rack cabinets and equipment delivery. (TIA, 2012) These parameters have been briefly summarized as follows for airport buildings:

- 1. Security:** The telecommunication rooms' design and location should be designed according to the general needs of the building according to TIA standards. In example, as underlined by Shevtsov, the main purpose of the airport building is to lead the passenger flow from landside to airside through security. Gordon (2004) has been also mentioned 9/11 attacks had become a groundbreaking tragic event for the existed airport security systems.

Therefore, IATA includes geopolitical tension as its main driver to discuss the risks and opportunities of the aviation industry for 2035. In airports, all telecommunication room doors require a lock or card access, which will be only used by the related technician or supervisor. (TIA, 2012)

2. **Location:** The location of the telecommunication room should be selected closer to the center point of the served area. (BICSI, 2020) TIA recommends not locating the telecommunications space in limited areas, such as remaining area surrounded by escape stairs, shear walls, elevators, etc. should not be preferred. These locations will limit future expansion and ease access to the room with large equipment. Additionally, the location shall be selected far from electromagnetic interference. (TIA, 2012) In airport buildings, to avoid dislocation of telecommunication spaces, the architectural and electrical teams should be involved location selection process to achieve effective coordination. (Alaloul et al., 2016)
3. **Access:** According to TIA standards, these rooms should be placed in an open, easily accessible area for the assigned technician.
4. **Pathways:** Sleeves or shaft openings for cabling has to be covered with a fire stopper after installation of cables. (TIA, 2012)
5. **Architectural design:**
 - a. **Plywood Backboards:** Minimum one 1.2 m x 2.4 m sheet plywood should be mounted on one wall of the telecommunication space for low voltage equipment.
 - b. **Ceiling:** Minimum 2.4 m height should be provided without any other installation. 3 m height from finished floor level (FFL) to the finished ceiling level (FCL) to allow installation of taller frames inside the room. TIA recommends having free overhead space without suspended ceiling.
 - c. **Treatment:** For all surfaces inside the room, dust minimizing applications have been recommended. For the finishing material color

TIA suggests brighter colors. Additionally, the finishing of the floor should be selected from an anti-static material pallet.

- d. **Floor Loading:** Floor should carry the required equipment load; therefore, structural calculations should be done and if required, reinforcement should be applied to the selected area.
 - e. **Lighting:** When technician is inside the room, there should be minimum 200 lux in the vertical plane and 500 lux in the horizontal plane. The control switches inside the room should be placed closer to the door. Lighting and telecommunication equipment should not use the same electrical distribution panel. (TIA, 2012)
 - f. **Door:** The minimum clear width should be 0.9 m and height should be 2 m without any obstacle. There should be no doorsill. If the door is hinged it should be open outwards (preferably 180 degrees as it is indicated in Figure 2.17). (TIA, 2012)
 - g. **Exterior Windows:** There should not be any exterior windows to prevent potential heat loss.
6. **Fire Protection:** Protection should be provided according to project requirement (local or global code), for example, NFPA requests 60 minutes resistance for wall and 45 minutes for door of the TRs. For MER and SER these values are increasing to 120 minutes and 90 minutes respectively. Dry fire suppression systems have been suggested by TIA, however, if wet pipe sprinkler systems have to be used, there should be protective wire cages to prevent false operation and there should be drain routes under the pipes to prevent unintended water leakage onto equipment. (TIA, 2012)
7. **Water Infiltration:** Telecommunication rooms could not be placed under wet areas. In the preliminary design phase, this should be considered immediately. (TIA, 2012)
8. **Racks and Cabinets:** Racks have been defined as a shelf which includes side rails for mounting of the equipment in TIA. Cabinets have been introduced as closets which have front and rear doors, and adjustable side rails.

- a. Clearances:** Minimum 1m clearance should be provided from front to install the equipment, but 1.2 m clearance has been suggested by TIA. Minimum clearance for rear of the cabinet or rack has been given as 0.6 m but again for better service quality, 1m has been recommended. (TIA, 2012) According to BICSI, 1m unobstructed space should be provided for equipment mounting on walls, racks, or cabinets.
- b. Cabinet Cooling:** Controlled air conditioning system should be discussed between mechanical and ICT team, in each room there should be a system to keep the room temperature at the desired level. (TIA, 2012)
- c. Cabinet and Rack Height:** 2.4 m should be the maximum rack height. For easier access of the agent, TIA recommends having 2.1 m height at most.
- d. Cabinet Depth and Width:** The dimensions of the cabinet should be defined according to the selected equipment. TIA suggests using 0.15 m wider or deeper cabinets from the selected equipment to provide space for cabling.
- e. Equipment Delivery:** Telecommunications equipment placement requires special factors, therefore, not only placing the room but also controlling the access routes of the rooms has played a crucial role. For instance, the clear width and the floor loading of the corridors should be considered. If there is a ramp, the slope should allow the equipment passage. (TIA, 2012)

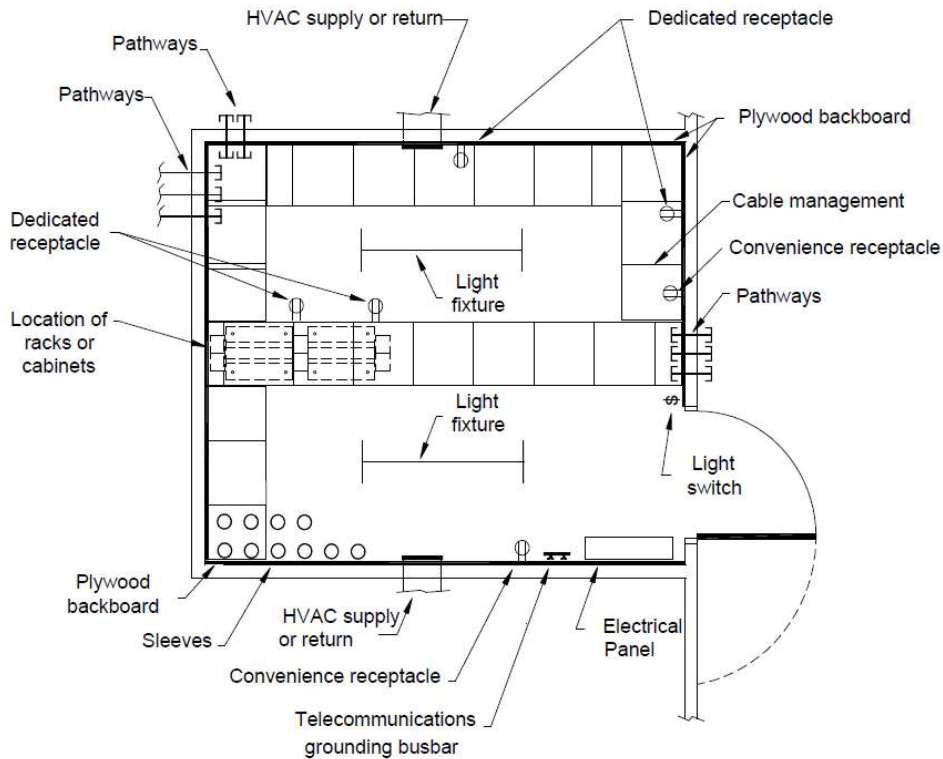


Figure 2.17 A typical telecommunication room layout (TIA, 2012)

2.2.3 BIM-Based Challenges in TR Coordination

The digitalization of the world also changed the conventional methods of building design and construction phases; therefore, the term Building Information Modeling (BIM) should not only be perceived as a technological improvement, but it should also be taken as a process innovation. (Eastman et al., 2011) NBIMS defines the BIM as digital portrait of structure with its physical and functional attributes. It provides a data warehouse where decision making process of the project could be reviewed during the building life cycle. (NBIMS, n.d.) The evolution of BIM has improved and revised the process of the coordination; however, the main aim is still completing the design coordination whilst providing the requirements of the project stakeholders. (Mehrbood et al., 2019) The coordination process of the project has required comprehensive knowledge regarding all building systems such as

mechanical, electrical, and plumbing systems. Even if BIM has enabled auto-detection of the possible clashes in digital environment prior to site implementation, to resolve the coordination problems multidisciplinary expert knowledge inputs have been required. (Korman et al., 2003)

As suggested by TIA Standards, early involvement of all parties plays a crucial role in achieving fully coordinated telecommunication spaces because the special requirements of these rooms have a direct relation with other disciplines. Additionally, the rapid change of technology requires a flexible design process for the telecommunication systems. (Pogorelskiy & Kocsis, 2022) However, like other disciplines, even if there are written standards, the proper coordination of the telecommunication spaces requires expert review and decision. (Mehrbod et al., 2019) Pogorelskiy has stated that because of the precision level of the types of equipment, the conventional 2D cabinet layouts and tray plans causes problems on site, therefore he has suggested to facilitate from the advantages of BIM.

Mehrbod et al. defines design coordination issues as complicated problem sets which could not be easily detected by automated clash detection and requires detailed review. Mechanical rooms, electrical panel rooms, shafts and telecommunication spaces could be given as an example for these complex areas. (Korman et al., 2003) All requirements and suggestions given by TIA and BICSI regarding with telecommunication spaces are related with layout decisions, clearances, and accessibility. These parameters could not be directly resolved or checked by using clash detection, the design coordination steps should be followed which are mentioned by Mehrbod (2019) as issue identification, issue resolution and issue documentation.



Figure 2.18 Three steps for BIM-based design coordination. (Mehrbod et al., 2019)

2.3 Ontology in Construction

The construction sector has grown day by day by leveraging the technological improvements and industry developments then crown this success with the complex structures like airports. (Edwards, 2005) Clients have requested architects to try the untested to be unique and the complicated geometry usage by architects have made engineers work on undiscovered calculations and solutions. Paper-based 2D coordination with all disciplines brought out conflicts on site and caused time and money loss for AEC industry. (Mehrbod et al., 2019) When the project construction time has been increased unwillingly, several studies have been conducted to determine the delay factors and categorized as employer-related, contractor-related, and external factors. (Bilgin & Birgonul, 2014) Soliman et al. (2020) adds that manual regulation checks have become more time-consuming tasks in complex projects and wrong data interpretation from a specification may bring out some errors which may cause rework and revisions. (Soliman-Junior et al., 2020) Therefore, the construction sector's research has been shifted to find a way to capture the learned lessons from previous projects and reuse the required knowledge of the experts in next ones. (Mehrbod et al., 2019)

2.3.1 Understanding the Need for Ontology in Construction Projects

Technological advancements have significantly reshaped the landscape of knowledge sharing within the construction industry by introducing Building Information Modeling (BIM) that revolutionizes project documentation, model sharing, and clash detection. According to Eastman et al. (2011), BIM serves as a central platform that enables the integration of various project dimensions, (from aesthetic concepts and functional requirements to economic considerations) and facilitates a holistic approach to construction project management. This evolution underscores the necessity of innovative knowledge management systems that serve to the increasing complexity and the need for specialized building systems to share expert knowledge effectively.

The digital age, especially marked by the emergence of the World Wide Web, has improved the development of these new knowledge management systems. As Costa & Lima (2014) have been emphasized, the advancements in digital technology demand strong communication channels between humans and machines, highlighting the importance of establishing a common vocabulary or dictionary for interdisciplinary project collaboration. This opinion is further supported by Schneider (2019), who argues that interoperability across different sectors, particularly in construction, necessitates the preparation of a shared lexicon to facilitate seamless communication among diverse disciplines.

The construction sector has encountered specific challenges because of required complex data exchange which have been categorized by Khudhair et al. (2023) under four topics; (i) the absence or partial implementation of data models, (ii) the lack of guidelines for developing data exchange tools, (iii) system corruptions due to incompatible software usage, and (iv) problems related to domain-specific datasets. These challenges underscore the critical role of ontology in construction projects, because it offers a structured information framework, which includes internal connections and hierarchical properties of the concepts, for architects and engineers

that supports common understanding among both human groups and computer programs. (Khudhair et al., 2023)

Moreover, the integration of semantic web features has facilitated the aggregation of information from various disciplines, enabling designers and engineers to systematically organize their knowledge. (Costa & Lima, 2014) This approach not only helps to address the aforementioned data exchange challenges but also simultaneously supports comprehensive decision-making processes that consider environmental, safety, and economic factors. (Khudhair et al., 2023) The incorporation of ontological principles into construction project management is not merely a technological necessity but a strategic requirement that enhances interdisciplinary collaboration and knowledge sharing. By establishing a shared understanding and facilitating efficient data exchange, ontology serves as a cornerstone for the evolving landscape of construction project management in the digital age. (Jin & Li, 2023)

2.3.2 Overview of Ontology Applications in Construction Projects

Several studies have been conducted related to the knowledge management to use the potential of ontologies in the construction sector. (Wetherill et al., 2002) Hsieh et al. (2015) underlined the complexity of the technical document review for earthquake engineering in construction projects and by using the information retrieval techniques, they aimed to define a domain ontology by using earthquake engineering specifications. The proposed fragmented domain ontology system that has been derived from reference collection of earthquake engineering documents, has provided clear knowledge representation with concept-based query answers. (Hsieh et al., 2015)

Nui, Issa and Mutis (2015) had drawn attention to the contract phase of the construction projects. It has been underscored that complex design and building systems have caused the complexity and risk increase in AEC projects which have

driven the industry to search for tools related with effective decision-making at contract stage. Researchers proposed a taxonomy development methodology for contract phase of the project, then checked the validity of the taxonomy by using a case study and they agreed that the methodology and the taxonomy itself could be used as a base for future ontologies. (Niu et al., 2015) Scholtenhuis and Hartmann (2015) highlighted the problems and delays because of the late involvement of the end-user. In the study, during the ontology development process, end-users have been involved, domain experts had a chance to explain the importance of the defined objects and relationships and end-users had an opportunity to indicate their perspectives. (Scholtenhuis & Hartmann, 2015)

Furthermore, there are several studies in the sector to capture the knowledge behind the manual tasks such as construction planning, compliance or regulation checking, quality control for building components, etc. Zhong et al. (2015) highlighted the importance of the construction planning for a successful building handover to the end-user. Two sub-processes have been indicated as the definition of the plan and the verification, and in their studies, an ontological approach has been presented to support these processes. (Zhong et al., 2015)

Zhong et al. (2012) and Jiang et al. (2022) worked on automated code and regulation checking for construction projects by proposing an ontological and semantic approaches. While these studies have been focused on improving the overall productivity of the overall project process, Qi and Costin (2023) have worked on an ontology-based framework for Design for Manufacture and Assembly (DfMA) of prefabricated or modular building components. They have focused on eliminating the lack of information sharing and problem detection, not sufficient processing of data and controlling the requirements. (Qi & Costin, 2023) The quality control process has a crucial role for the building components and as Jia et al. (2023) underlined, conventionally paper-based technological specifications and procedure explanations have been used. The reuse of this non-systematic expression of the information and the possible necessary modification in the procedure requires human analysis. Therefore, to decrease the possible faults which could be faced because of

not being familiar with the documentation, a semantic framework has been proposed for information modeling and application in construction projects. (Jia et al., 2023)

The construction of ontologies plays a critical role in the fields of artificial intelligence and knowledge management, offering a structured framework for representing and organizing complex data and relationships within various domains. As the need for seamless information exchange and interoperability grows across diverse sectors, particularly in Architecture, Engineering, and Construction (AEC), ontologies provide the backbone for capturing, sharing, and utilizing domain-specific knowledge effectively. In the following section, two studies by Jia et al. (2023) and Zhong et al. (2015) are to be examined in detail in terms of ontology creation methods.

2.3.3 Steps of Developing an Ontology

Ontology formally abstracts and simplifies a specific domain, outlining its essential objects, concepts, their relationships, and the logical axioms that govern these elements. (Noy & McGuinness, 2001) Unlike relational databases and XML schemas that lack explicit semantic expression, ontologies clarify and share the deep semantics of information, allowing for complex reasoning. They are adaptable data structures that facilitate the computer-readable interpretation of knowledge through formalized semantics. (Zhong et al., 2015)

The Semantic Web, leveraging the Web Ontology Language (OWL) and the Resource Description Framework (RDF), facilitates the structured expression of data across the World Wide Web, enabling both machines and humans to interpret complex information consistently. Through OWL, data gains precise definition, while RDF provides a framework for contextualizing this data, enhancing interoperability. Additionally, the Semantic Web Rule Language (SWRL) complements OWL by introducing rule-based logic for advanced data inference, enriching the semantic understanding. (W3C, 2004) Both Zhong et al. (2015) and Jia

et al. (2023) have highlighted that in construction projects, this integrated approach significantly streamlines the sharing, retrieval, and adaptive reuse of technical planning and regulatory compliance information, promoting efficient communication among stakeholders and aligning with dynamic project requirements.

For the ontology study related to the quality control process, the process and normative information models for the AEC industry which were established to store the building code knowledge have been presented by Jia et al. (2023) to highlight the industry acquisitions from ontology and semantic web technology. The framework, which has been presented for information modeling and process application of building components, consists of an ontology layer and semantic reasoning layer. (Jia et al., 2023) First, the ontology methodology has been developed by using the strengths from seven-step method and Methontology (Fernandez et al., 1997). In Figure 2.19, the merged ontology method that has been used by Jia et al. (2023) has been indicated.

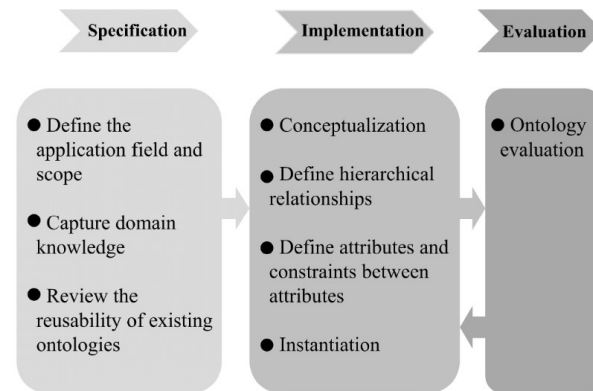


Figure 2.19 Schematic ontology development diagram (Jia et al., 2023)

At the specification phase, the application field of ontology has been clarified as construction process information, which was specifically utilized in the building construction domain, concentrating on unifying knowledge concerning the construction procedures for a wide range of building elements. Existing ontologies have been reviewed in detail; however, Jia et al. (2023) have decided to redevelop

an ontology because there was not any concentrated ontology related to various types of building components.

At the implementation phase, firstly for the conceptualization, three level ontology development has been planned which will ease the reuse of the ontology for different building components. The specialization level of the ontology has been increasing from top to bottom, as could be seen from Figure 2.20. At the top-level ontology, domain terminology, construction process, standard, product, construction materials, construction tools, key measures and component concepts have been included which were the key elements that were identified by domain experts. These concepts have clarified specialized terms used in construction, detailed the necessary resources and standards, and explained the execution of construction tasks. They have also made a clear distinction between final construction products and their components to avoid confusion. (Jia et al., 2023)

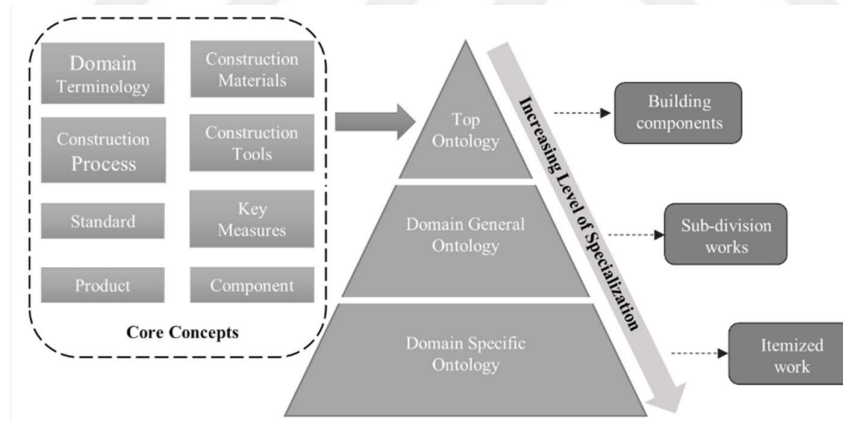


Figure 2.20 Multi level ontology for construction process of building components. (Jia et al., 2023)

For the second step, DiCon, which is one of the existing construction ontologies, has been used to define semantic relationships between concepts. (Törmä, 2021) The main idea behind the denomination is using the pure meaning of the name, to make the understanding clear for the user. As it is indicated in Figure 2.21, Jia et al. (2023) have represented the kernel semantic framework for the top-level ontology by these concepts and their relationships.

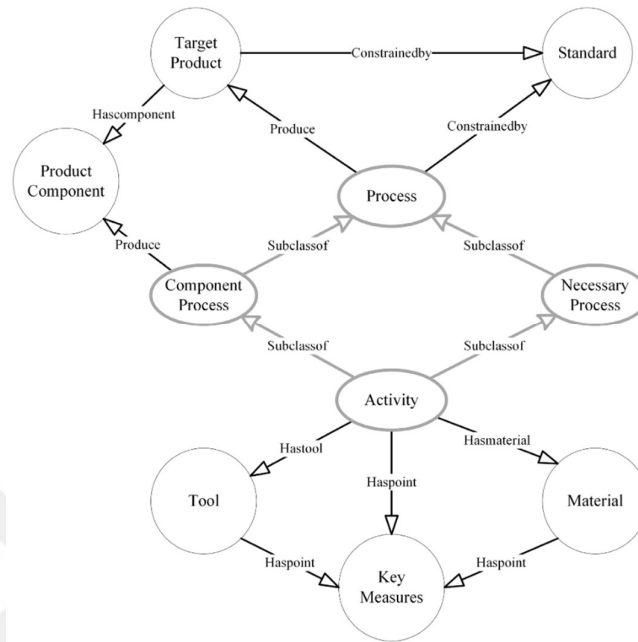


Figure 2.21 Process knowledge model for construction process. (Jia et al., 2023)

After defining top-level ontology, a domain general ontology has been developed in detail for masonry wall engineering as an example of a sub-division work. The related standards have been used for domain knowledge and the construction process activities/relations have been conceptualized according to the expert experiences. (Figure 2.22) By this way, the relations between concepts and samples have been introduced as a base which could be used in future as a template. (Jia et al., 2023)

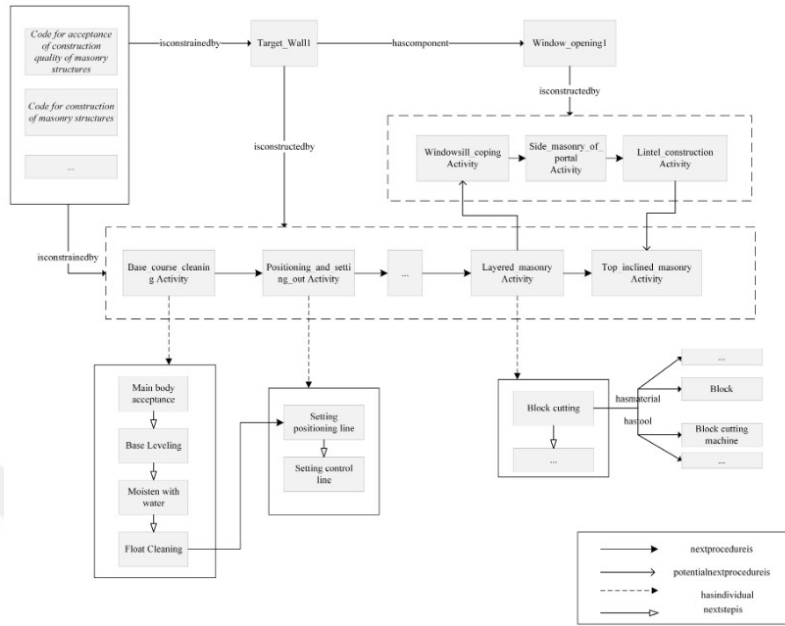


Figure 2.22 Construction process of the wall masonry (Jia et al., 2023)

For the ontology evaluation, Jia et al. (2023) have introduced a semantic reasoning layer in machine-interpretable language to represent validation, constraint, and query rules. By this way, the constraints related to the target building component and its construction process could be controlled without human interaction. The construction process of the masonry has transferred to an ontology by using the OWL language. The concepts have defined the classes and the relationships between the classes and the objects have been defined with object properties. This OWL ontology has been adopted to the SWRL language for the rule modeling because of its ability to exceed the reasoning and description limitations of the OWL language. (Jia et al., 2023) For the ontology implementation and validation, Protégé has been used as a platform. The evaluation of the consistency, the reasoning of the process rules and the query mechanism has been finalized with the help of some add-ins like Drools and SPARQL. This study showed that this presented method expedites the reusable data collection and the control of the knowledge in the construction processes. (Jia et al., 2023)

For an ontological approach to define and verify the construction plan, Zhong et al. (2015) have proposed a four-level framework which consists of ontology layer, schema layer, representation & reasoning layer, and application layer. A meta-model for the technical domain (Figure 2.23), which can be also expanded from each concept to sub-ontologies, has been presented.

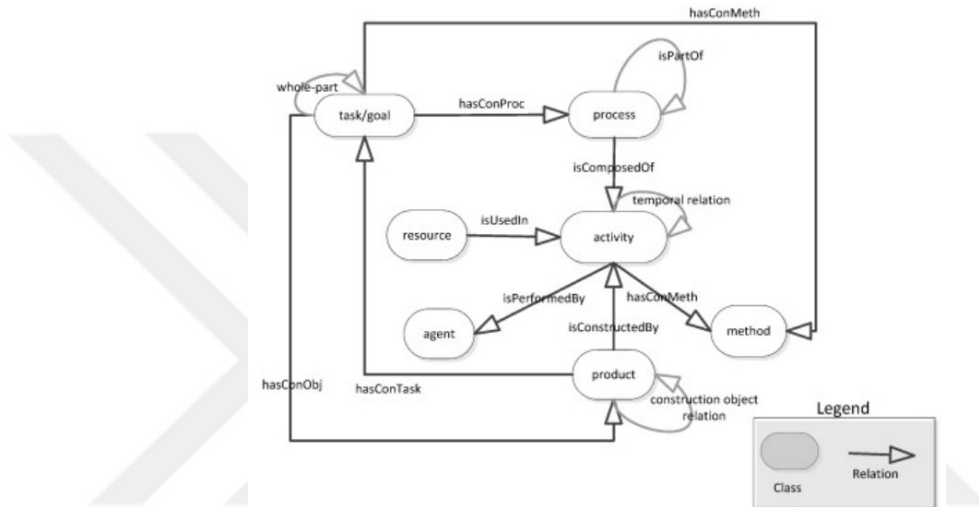


Figure 2.23 Construction plan knowledge diagram (Zhong et al., 2015)

For the rule set of the technical plans, a constraint domain which has been taken from building codes and regulations has been listed. Zhong et al. (2015) created a template by using the Resource Description Framework (RDF) to demonstrate the technical plan of the deep foundation pit excavation engineering and to represent the constraints they selected Semantic Web Rule Language (SWRL) which is integrated with OWL. The plan information has been shown as instances in OWL and the rule sets have been defined in OWL axioms and SWRL rules. (Zhong et al., 2015) For the validation and the reasoning of the plan definition, the Protégé platform and JESS engine have been utilized as indicated in Figure 2.24.

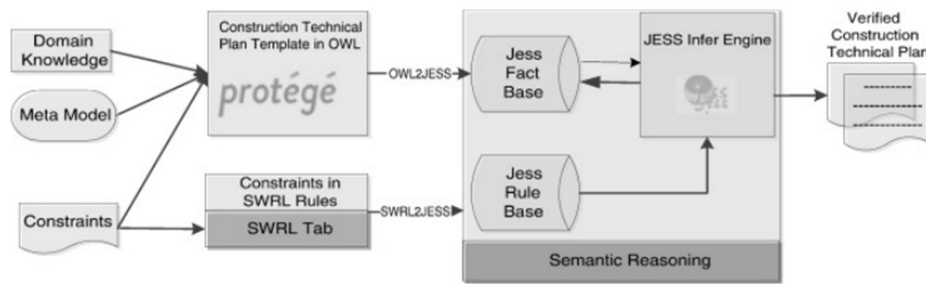


Figure 2.24 Plan definition and verification in Protégé by JESS. (Zhong et al., 2015)

2.3.4 Future of Ontology in Construction Sector

The promising features of semantic web technologies have raised the interest in ontology-based methodologies in AEC industry, to take advantage of integrating the different knowledge domains from various disciplines. (Schneider, 2019) As it is faced in other technological developments, Schneider (2019) underlined that the wide and rapid spread of the ontology taxonomy creation leads the industry to work on the ontology matching systems to eliminate the overlapping domains for collecting all ontology frameworks under one roof. Similarly, Hsieh et al. highlighted the importance of the quality check for proposed ontologies and suggested user-search trials for domain-specific ontologies. Scholtenhuis & Hartmann (2015) and Niu et al. (2015) discussed in their studies that proposed and studied taxonomies should be enriched and validate with several other projects to encompass their specific fields.

The Linked Building Data Community Group (LBD-CG) of the World Wide Web Consortium (W3C) explores the way to construct a web based common library and information sharing platform for existing and developing ontologies for Architecture, Engineering, Construction, Owner, and Operation (AECOO) industry. (Rasmussen et al., 2020) The Building Topology Ontology (BOT) has been introduced as a main set which could include a high-level description for industry related taxonomies, building elements, 3D models with linked ontologies from other

disciplines. Rasmussen et al. (2020) have highlighted that BOT could support Level 3 BIM implementations persistently in the AECOO industry if contributions and improvement efforts continue without interruption. Additionally, Lima et al. (2007) also discussed the steps required for the construction industry to harness the Semantic Web—a web of data that enables machines to understand and respond to complex human requests based on their meaning. This necessitates to ensure the industry's information and processes are semantically enriched and interoperable as it has been aimed by LBD-CG, W3C (Rasmussen et al., 2020) and IFC schema. (Costa & Lima, 2014)

In conclusion, the future expectations from ontology implementations in the construction sector are to bring about significant improvements in knowledge sharing, data interoperability, decision-making processes, collaboration among project teams, project outcomes, cost reduction, sustainability, and compliance with laws and regulations. (Jia et al., 2023) (Zhong et al., 2012) These implementations are expected to revolutionize the way construction projects are managed, leading to increased efficiency and productivity in the industry. As it is underlined in the study by Rezgui Y et al. (2011), the future of ontology usage in the construction industry, envisioning technological solutions that will support team collaboration in the sector. These solutions are proposed to be delivered as web services, offering customizable, scalable, and user-friendly environments. They summarized the key points which could be improved for the usage of the ontologies in construction sector as follows:

1. The support for seamless electronic processes and higher-order functionality by composing services from elementary services that are available anytime, anywhere through a web browser.
2. The potential need for flexible mechanisms that allow for the rapid combination of multiple discipline ontologies into a single view to accommodate users who deal with more than one discipline ontology.
3. Underlining the importance of the evolution from data products to knowledge-rich ontologies and their role in supporting business processes in construction projects. (Rezgui et al., 2011)

CHAPTER 3

SURVEY

A comprehensive literature review has clearly outlined that complex projects like airports comprised of complicated building systems such as information communications technology (ICT) require the interoperability of all disciplines. Concurrently, this challenging coordination process between parties necessitates structured frameworks for decision-making without any contradiction in the entire project life cycle. Architects and engineers are the main real-life characters who try to solve these labyrinths, therefore their expertise related to the research topic and their opinions on the research aim and objectives are key components of this study. A survey, consisting of both quantitative and qualitative questions, was designed to collect their expert knowledge related to findings of the literature review, discussing the current coordination techniques and the bottlenecks in the process.

The goal of the survey is to clarify the steps of the telecommunication rooms (TRs) coordination process and collect expert reviews related to productivity levels of these stages. The objectives and results obtained from previous studies in the literature were questioned with survey questions in line with the purpose of the research. The objectives of this survey can be listed as follows.

1. Verify the TR coordination rules which were identified by literature review.
2. Collect the contribution phases data of the parties to develop the TR coordination relationship map.
3. Identify the issues related to the TR coordination process.
4. Explore the importance of the information sharing between engineers and architects related to ICT.

3.1 Survey Structure

The survey included 13 multiple choice questions and 2 open ended questions to collect both quantitative and qualitative data from industry experts. Detailed explanation for each question is listed as follows.

- Q1: General information related to participants and their company.
- Q2: Asked for defining their company role in the project.
- Q3: Asked to identify the size of their company.
- Q4: Asked for understanding the ICT related employee number in their company.
- Q5: Asked for defining their company's project involvement phase.
- Q6: Asked for clarifying the communication path to define TR Coordination rule sets for the project.
- Q7: Asked for learning the BIM implementation phase for their company.
- Q8: Asked for understanding which communication and representation techniques have been used to define the TR coordination rule sets.
- Q9: Asked for evaluating the effectiveness of the knowledge sources and communication techniques for defining TR coordination rule sets.
- Q10: Asked for defining the project phase when TR coordination rule sets have been frozen for site works.
- Q11: Asked as an open-ended question to get the experts' thoughts on possible improvement in the TR coordination process by using pre-defined rule and action sets.
- Q12: Asked for defining which project phases could be optimized by using pre-defined rule sets.
- Q13: Asked for defining the possible affected phases and sub-categories of these phases from TR coordination rule set changes.
- Q14: Asked as an open-ended question to get the experts' thoughts on the current interest level for ICT in the sector.

- Q15: Asked to understand in which phase required importance should be given to ICT.
- Q16: Asked to understand that is there any difference regarding the importance of the ICT between airports and other buildings.

3.2 Survey Procedure and Findings

This survey was conducted with industry experts who have worked on construction projects and have a role in the TR coordination process. The aim of the study was explained at the beginning of the survey and instructions were shared via e-mail. Application to the Ethics Committee was completed on 1/12/2023 and accepted on 18/01/2024.

Of 13 industry experts receiving the survey, 11 completed providing their valuable contributions to the study.

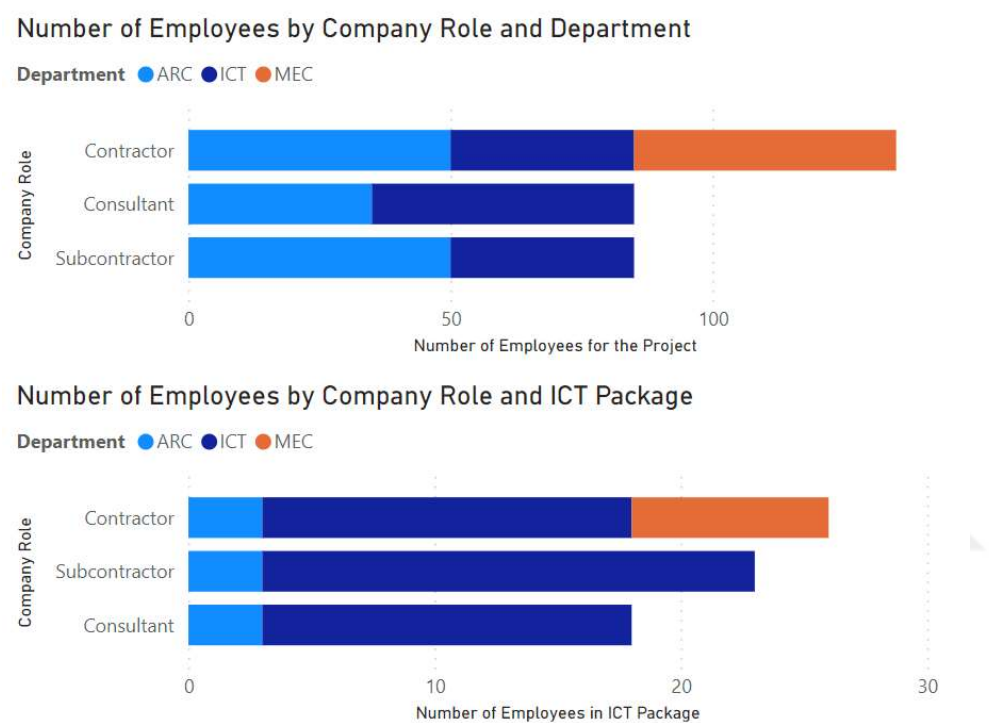
3.2.1 Participant Characteristics and Company Profiles

The participant group has been selected from Kuwait International Airport Terminal 2 project which includes 708.000 sqm construction area. The participants of the surveys are individuals working in the aviation industry as architects, ICT engineers or mechanical engineers at the construction site for the sub-contractor, contractor, or consultant companies. Overall, seven companies were identified in the survey which are employed as consultants, contractors, or sub-contractors.

Four companies have between 21 to 50 employees and three companies have more than 50 employees for this project. After participants asked for the number of employees that had been assigned for ICT coordination, it was determined that the size of the ICT department of the contractor and ICT consultant varied between 11 to 20, meanwhile ICT subcontractor has over 20 employees. On the contrary, the design consultant, contractor and subcontractor have been assigned between 2 to 5

architects and design coordinator for ICT coordination. Table 3.1 indicates the graphs to show the ICT employee number ratio difference between design/construction companies and ICT companies.

Table 3.1 Company Profiles of the Participants



3.2.2 Findings from the Survey – Quantitative Results

All companies included in the survey have been appointed for the project after concept design phase. (Stage 2 in Figure 3.1 according to RIBA Plan of Work 2020) However, since the beginning of the project (Stage 0-1), there has always been communication between the design consultant and the client for briefings on the project. The participants were asked about their communication with other roles, and it has been noted that there has been active communication between consultant-contractor-subcontractors at each stage before the construction phase. (between

Stage 3 to Stage 5) Closer to construction stage, there has been an end-user involvement.

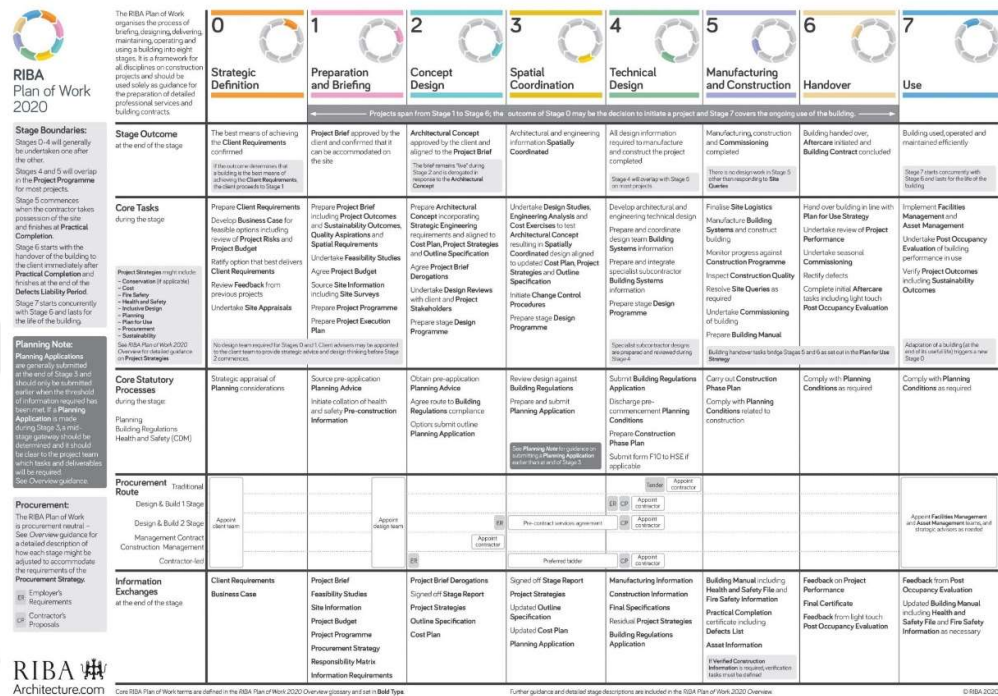
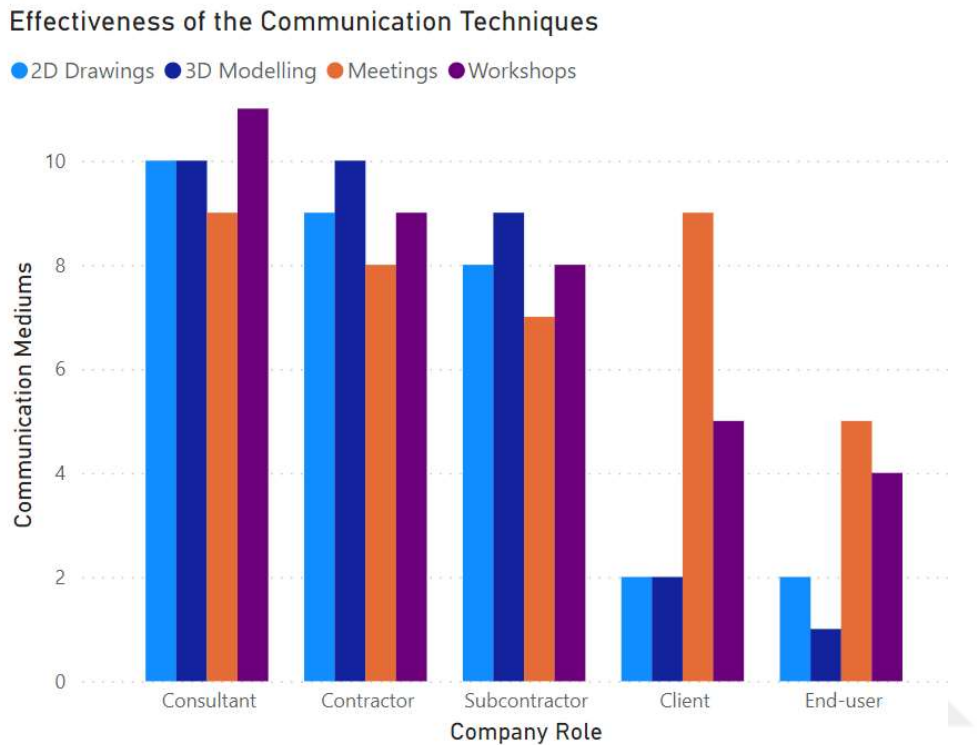


Figure 3.1 RIBA Plan of Work 2020

Participants were asked about which techniques and instruments they used for communicating between each other, the client, and the end-user. It was noticed that even if the consultant, contractor, and subcontractors have been using all communication techniques (meetings, workshops, 2D drawings and 3D models), when it comes to discussion with the client and end-user, consultants have only been using meetings and workshops.

Table 3.2 Communication Methods Table with Company Roles



In the survey, the participants were asked about the effectiveness of the mediums to define the telecommunication rooms coordination rule sets, and it was observed that the consultant, ICT and Mechanical department of the contractor, and ICT subcontractor have found project specifications and related standards such as BICSI and TIA very efficient. They rated meetings, workshops and 2D drawings as less effective. In contrast, the design team of the contractor and design subcontractor selected meetings, workshops, 2D drawings and 3D models as much more effective than specifications and standards.

All participants indicated that in their current project the TR coordination rule sets have been defined right before the construction phase (Stage 5). They clearly mentioned that if there is a pre-defined rule sets for constraints and actions, from the concept design phase of the project there will be an acceleration. Additionally, the results indicate that if there is a change in the rule sets in the later stages of the

project, there is a direct impact to the beginning of the spatial coordination stage of the project.

To understand if there is a difference between airport projects and the other types of buildings, the industry experts have been asked about the importance of ICT coordination in the construction sector in two different questions. It was noted that all participants agree that the significance of the ICT should be understood by all parties before the spatial coordination stage.

3.2.3 Findings from the Survey – Qualitative Results

The qualitative part of the survey included two open ended questions, designed to collect the industry experts' thoughts about the possible effectiveness of the pre-defined rule sets for the TR coordination and the perceived importance of the ICT in the construction sector. Regardless of their department and role in the project, the majority of participants agreed that the most important but disregarded part of the TR coordination is sharing the knowledge with all parties in the earlier stages of the project. This underlines that pre-defined rule sets will accelerate the proper coordination process from Stage 1. Additionally, the results highlight that ICT systems are not given sufficient consideration in buildings, especially in airport constructions and this causes a lot of rework and time loss for ancestor or predecessor activities.

3.3 Discussion on Findings

Analysis of the survey results indicated that there is a complex relationship between agents, methods, and resources in TR coordination processes. The collected data used for demonstrating the coordination steps at the below diagram in Figure 3.2.

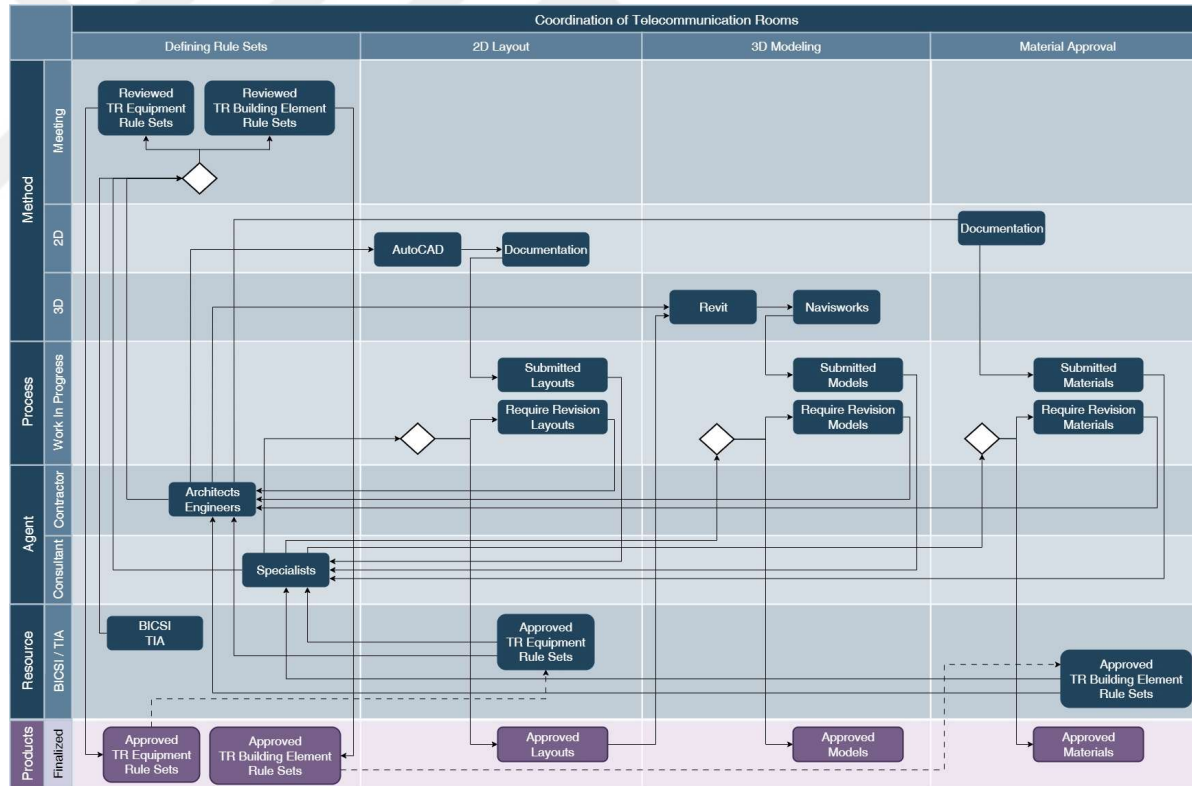


Figure 3.2 Swimlane diagram of existing TR coordination steps.

As demonstrated in the diagram, the coordination process for TRs in airport construction projects is intricate, involving multiple revisions and agent interactions. This complex web of activities underscores the necessity for a more streamlined approach. Chapter 4 introduces ontology development methods tailored for the construction industry, which could potentially simplify and enhance these processes. By employing a structured ontological framework, the study aims to develop predefined rule sets that can optimize interactions and reduce the need for frequent revisions, thereby improving overall efficiency and coordination among parties.



CHAPTER 4

MATERIAL AND METHOD

The main aim of this study is to develop a pre-defined rule set to accelerate and improve the telecommunications room coordination process in BIM-based airport projects. In this chapter, the selected ontology development methods which have been utilized for construction industry and assistant software types for implementing and validating the framework will be presented.

4.1 Ontology Development Method

There are several ontology development methods used for different sectors, however, for the construction industry, as it has been underlined in literature review, the main objectives could be summarized as; to gather the knowledge from specifications and experts' implicit knowledge and to record the coordination process including relationships between decision makers and controllers. For instance, Jia et al. (2023) focused on creating a merged ontology method, which has been created from the strengths of Methontology and seven-step methods, to collect process knowledge for building components. On one hand, Methontology provides a framework for developing ontologies at the knowledge level and it is different from other ontology methods because it emphasizes documenting the ontology development process and its outcomes. (Fernandez et al., 1997) On the other hand, the seven-step method is a more task-oriented approach to ontology development, which focuses on breaking down the process into series of manageable tasks. (Kamel et al., 2007) Both methodologies are domain-agnostic, and they could be applied to develop ontologies across various fields and disciplines.

As it is discussed in literature review, numerous studies have been conducted to define domain-specific ontologies to improve specific fields related to the construction sector. Especially for BIM-based projects, utilization of the IFC schemas facilitates common language usage. (Jiang et al., 2022) Similarly, Costa and Lima (2014) used main IFC schema (i.e. ifcOWL) to define their major classes in their domain ontology which aims to support collaborative engineering in AEC sector. However, because there is not enough lexicon for each branch under IFC construction schemas yet, some of the researchers developed their own classes, individuals and relations which could be converted in IFC (currently it is IFC4), or they used directly IFC naming standards.

In this thesis study, the main aims have been defined as (i) capturing the TR coordination process in BIM-based airport projects and (ii) providing a formal model for TR layout rule sets in OWL (Web Ontology Language). Therefore, two hierarchical ontologies will be developed. The first ontology will be a top ontology including main classes which have roles in TR coordination process in BIM-based airport projects. Because it will focus on directly recording the actions in BIM environment; IFC schema is to be used as a base for defining classes and seven-step method to create a work breakdown structure for coordination process. The second ontology will be a domain specific ontology which consists of TR layout rules derived from BICSI and TIA specifications. The Methontology method will be used as this ontology will focus on archiving constraint rules and will be reviewed and revised (if necessary) at the beginning of the project.

4.1.1 Top Ontology

The Industry Foundation Classes (IFC) schema is a comprehensive data model developed by buildingSMART International for representing, sharing, and exchanging information in the building and construction industry. IFC is designed to facilitate interoperability among different software applications used in the design, construction, and operation of buildings and other built assets. The schema is based

on an object-oriented and entity-relationship model that encompasses various aspects of construction projects, including the physical and functional characteristics of a building and its components, as well as the project management and organizational aspects. (Costa & Lima, 2014) In this study, main domains classes of the top-level ontology will be drawn from IFC Schema, and the seven-step method will be used for the methodology of the ontology construction. The steps are as follows:

Step 1. The definition of the scope of the ontology: Telecommunications room coordination rules and relations to reach improved process for architects and engineers in airport construction sector.

Step 2. The search for the existing ontologies: Not to duplicate, do research for existing ontologies which might be used for the defined scope, or which might include a related ontology domain.

Step 3. Enumerating important terms in the ontology: To define the concepts, objects, entities, and relations related to the telecommunication rooms, standards from the sector (BICSI, TIA and Building Specifications) will be used.

Step 4. Defining the classes and the class hierarchy: Organizing the related TR terms into classes (or concepts) and defining the hierarchical structure among them, typically using a subclass (is-a) relationship.

Step 5. Defining the properties of classes: Defining the properties of these classes. Properties describe the characteristics of the classes or the relationships between classes. This includes defining attributes and relationships between instances of classes.

Step 6. Defining the constraints of the properties: Providing additional details about the properties like allowed range of values, default values and cardinality. This step is crucial for ensuring the accuracy and consistency of the data that will be represented using ontology. The value types could be summarized as string, number, Boolean, enumerated or instance. (Noy & McGuinness, 2001)

Step 7. Creating instances for validation: Populate the classes of the ontology with specific elements (instances). This involves creating concrete examples of the classes defined in the ontology, thereby representing actual data. Instances are often used to validate the ontology structure and to begin using the ontology for its intended purposes.

4.1.1.1 Top Ontology Construction

In this study, after defining the scope (**Step 1**) of the ontology as TR coordination rules and relations in airport projects for architects and engineers, as mentioned before, the class naming for top level ontology has been inspired from the IFC schema (**Step 2**). To enumerate the terms for top level ontology (**Step 3**) and to define the class hierarchy (**Step 4**), the following breakdown was developed according to BICSI/TIA recommendations, and according to the process knowledge from industry experts which were discussed in Chapter 3.

Step 4. Classes and their sub-classes in natural language:

1. **Task:** *A starting point which is the initial objective or requirement in the coordination.*
 - 1.1. Creating fully coordinated layouts, models, and material lists for telecommunication rooms in airport project.
2. **Process:** *A process which includes the sequence of activities undertaken to achieve the task.*
 - 2.1. Drafting Process
 - 2.1.1. The 2D TR layouts are to be drafted by contractor agents and submitted to consultant agents for evaluation.
 - 2.1.2. The 3D TR models are to be drafted by contractor agents and submitted to consultant agents for evaluation.
 - 2.1.3. The TR building elements material lists are to be drafted by contractor agents and submitted to consultant agents for evaluation.
 - 2.2. Evaluation Process

- 2.2.1. This is the first step of the TR coordination. The pre-defined rule sets for TR coordination are to be evaluated and marked as "Accepted" or "Not Accepted" by a consultant agent.
- 2.2.2. The submitted 2D TR layouts are to be evaluated and marked as "Accepted" or "Not Accepted" by a consultant agent.
- 2.2.3. The submitted 3D TR models are to be evaluated and marked as "Accepted" or "Not Accepted" by a consultant agent.
- 2.2.4. The submitted TR material lists are to be evaluated and marked as "Accepted" or "Not Accepted" by a consultant agent.
- 2.3. Revision Process
 - 2.3.1. The "Not Accepted" marked 2D TR layouts are to be revised for resubmission for evaluation.
 - 2.3.2. The "Not Accepted" marked 3D TR models are to be revised for resubmission for evaluation.
 - 2.3.3. The "Not Accepted" marked TR material lists are to be revised for resubmission for evaluation.
 - 2.3.4. The pre-defined rule sets for TR coordination are to be revised according to requests from evaluation.
- 3. Product:** *A stopping point which is the output or result of the process.*
 {2D_TR1001,2D_TR1002,...,2D_TR1015,3D_TR1001,...,3DTR1015,
 TREquipment, TRBuildingElements}
 - 3.1. Approved rule sets.
 - 3.2. Approved 2D layout.
 - 3.3. Approved 3D model.
 - 3.4. Approved material lists.
- 4. Resource:** *An input which includes the knowledge sources used in the activities.*
 - 4.1. BICSI, TIA and Building Specifications.
 - 4.2. The rule set related to TR equipment types and their spatial constraints.
 - 4.3. The rule set related to properties of TR building element materials.

5. Agent: *An input which includes the individuals or entities performing the activities.*

5.1. Contractor={Alpha, Bravo, Charlie, Delta, Echo}

5.2. Consultant={Foxtrot, Golf, Hotel, India, Juliet}

6. Method: *A process way which serves the approach, or a technique used for a process.*

{Meeting, AutoCAD, Revit, Navisworks, Documentation}

Step 5. Relations between classes in natural language:

- Task has a coordination process leading to Process.
- Activities are the subclasses of the Process.
- Process uses Resource, is performed by Agent, has a coordination method leading to Method, and constructs Product.
- Activities have temporal relations, suggesting sequence or order.
- Task has a coordination objective leading to Product.

Object Properties of the relations:

- 1. hasCoorProc (Task to Process):** A functional property since each task initiates a unique coordination process. **(inverse of: isObjectOf)**
- 2. isUsedIn (resource to Process):** Process uses resources which is not necessarily a functional property since one activity might use multiple resources. **(inverse of: uses)**
- 3. isPerformedBy (Process to Agent):** Describes which agent (or agents) performs an activity. This relationship may not be functional because an activity can be performed by multiple agents. **(inverse of: performs)**
- 4. hasCoorMethod (Process to Method):** This indicated the methods used for different coordination steps. **(inverse of: isCoorMethodFor)**
- 5. isConstructedBy (Product to Process):** Indicates which activity leads to the creation of a particular product. **(inverse of: constructs)**

6. **isEvaluateBy/isDraftedBy (Process to Agent):** Illustrates the different activities that different groups (consultant and contractor) perform for process. **(inverse of: evaluates/drafts)**
7. **isMethodForEvaluate/isMethodForDraft (Method to Process):** Indicates different methods used by different groups for specific activities. **(inverse of: hasEvaluationMethod/hasDraftMethod)**
8. **hasCoorObjective (Task to Product):** Describes that task has specific aim(s) constructed by process. **(inverse of: isObjectOf)**

Because it is a top-level ontology, all relationships are generally expressed as instance/object type (**Step 6**). They represent links between instances of classes in the ontology rather than constant values like strings or numbers. In the domain specific ontology section, different types of property constraints are to be held. Additionally, **Step 7**, which includes populating the instances into ontology classes is demonstrated inside **Step 4** list between braces (curly brackets) under related classes. For this top-level ontology, only data properties for instances in process class have been defined because by using these inputs the classification of individuals into process subclasses are to be held by SWRL rules which will be explained further. The data properties for drafts have been named as submissionStatus, evaluationStatus, roomArea and riskStatus. After completing all the steps like Jia et al. (2023), the main framework for all classes and generic relationships between them was established for TR coordination.

4.1.1.2 Top Ontology Semantic Model Representation

OWL allows for the detailed representation of the TR coordination process in a format that computers can interpret. For instance, the task “creating fully coordinated TR Layouts” has a coordination process which includes a sequence of activities under process class and the process has to perform by minimum one agent. These relations are essential to create a main framework for coordination processes, in this case, this framework will be customized for use in TR coordination. The following

XML fragment outlines how OWL could articulate the structural knowledge of the process, including the definition of classes and the relationships (object properties) between them. This adaptation demonstrates OWL's capability to represent complex knowledge within the TR coordination, facilitating computerized understanding and processing. At the following XML section, “Task – has coordination process – Process” and “Process – is performed by – Agent” relations have been demonstrated as samples.

<!-- Classes and Object Properties -->

```
<owl:Class rdf:about="trcoor:Task"/>
```

```
<owl:Class rdf:about="trcoor:Process"/>
```

```
<owl:Class rdf:about="trcoor:Agent"/>
```

```
<owl:ObjectProperty rdf:about="trcoor:hasCoorProcess"/>
```

```
<owl:ObjectProperty rdf:about="trcoor:isPerformedBy"/>
```

<!-- Adding a restriction to define the object property between classes -->

```
<owl:Class rdf:about="trcoor:Task">
```

```
  <rdfs:subClassOf>
```

```
    <owl:Restriction>
```

```
      <owl:onProperty rdf:resource="trcoor:hasCoorProcess"/>
```

```
      <owl:someValuesFrom rdf:resource="trcoor:Process"/>
```

```
    </owl:Restriction>
```

```
  </rdfs:subClassOf>
```

```
</owl:Class>
```

```
<owl:Class rdf:about="trcoor:Process">
```

```
  <rdfs:subClassOf>
```

```

<owl:Restriction>

    <owl:onProperty rdf:resource="trcoor:isPerformedBy"/>

    <owl:someValuesFrom rdf:resource="trcoor:Agent"/>

</owl:Restriction>

</rdfs:subClassOf>

</owl:Class>

```

4.1.1.3 Top Ontology Semantic Rule Modeling

At the top-level ontology, to indicate the sequence between activities under process class, the strength of SWRL rules have been utilized. The classification has been made according to the used method and submission status of the draft individual which is a member of process class. For that purpose, the submissionStatus data property and hasDraftMethod object property have been defined. Following SWRL rules are some examples to automatically define the subclass of the draft individuals. All rules will be indicated in the following ontology implementation section.

Rule 01. *Process(?p) ^ submissionStatus(?p, "workInProgress") ^ hasDraftMethod(?p, AutoCAD) -> Draft2DActivity(?p)*

This rule states that if a draft individual has AutoCAD as a drafting method and its submission status is indicated as “work in progress” then it should be a member of the Draft2DActivity class.

Rule 02. *Process(?p) ^ submissionStatus(?p, "submitted") ^ hasDraftMethod(?p, AutoCAD) -> Evaluate2DActivity(?p)*

This rule states that if a draft individual has AutoCAD as a drafting method and its submission status is indicated as “submitted” then it should be a member of the Evaluate2DActivity class, i.e. by this way assigned agent could reach the layout for review.

Rule 10. *Process(?p) ^ submissionStatus(?p, "submitted") ^ hasEvaluationMethod(?p, Meeting) -> EvaluateRuleSetsActivity(?p)*

This rule defines that if a draft individual has “Meeting” as an evaluation method and its submission status is indicated as “submitted” then it should be a member of the EvaluateRuleSetsActivity class.

Rule 11. *Process(?p) ^ evaluationStatus(?p, "Accepted") ^ hasEvaluationMethod(?p, Meeting) -> Resources(?p)*

This rule defines that if a draft individual has “Meeting” as an evaluation method and its evaluation status is indicated as “accepted” then it should be a member of the Resource class which is to be used in rest of the processes.

Rule 12. *Process(?p) ^ roomArea(?p, ?ra) ^ swrlb:lessThan(?ra, 12) -> riskStatus(?p, "High")*

This rule automatically checks the area values of the rooms before coordination initiates and if it is smaller than the optimum (closer to minimum) required sqm (according to reviewed and defined rule set), it fills the riskStatus data property assertion as “High” which gives a prewarning to the agent who will coordinate the room.

4.1.2 Domain Specific Ontology

As is highlighted in the previous studies, not to create duplicates, existing ontologies have been reviewed for the development of second ontology as well. However, it has been observed that there is no defined ontology for spatial coordination of specific technical rooms. This domain specific ontology should provide a formal model in OWL for the rule sets which is currently reachable in BICSI and TIA in natural language. As mentioned before, because this ontology will focus on archiving the constraint rules explicitly and will be reviewed and revised by engineers and architects (if necessary) at the beginning of the coordination process, Methontology

method will be used due to its strengths. Methontology steps could be broken down as follows: (Fernandez et al., 1997)

Step 1. Specification: Defining the purpose, scope, and requirements of the ontology, including who will use it and for what reason.

Step 2. Knowledge Acquisition: Gathering information from various sources like domain experts, specifications, and existing databases.

Step 3. Conceptualization: Organizing and structuring the gathered knowledge into a conceptual model, identifying key concepts, entities, and their relationships.

Step 4. Formalization: Translating the conceptual model into a formal or semi-formal representation using appropriate ontology languages.

Step 5. Integration: Incorporating or aligning the ontology with existing ontologies where applicable, to promote reuse and interoperability.

Step 6. Implementation: Using ontology development tools to encode the formalized model into a computationally usable form.

Step 7. Evaluation: Reviewing the ontology against predefined criteria like integrity, consistency, and relevance to ensure it complies with the purpose.

Step 8. Documentation: Providing comprehensive documentation detailing the ontology's purpose, structure, and use, facilitating understanding and adoption by others.

Step 9. Maintenance: Regularly update and refine the ontology to incorporate new knowledge, correct errors, and ensure it remains relevant and accurate over time.

4.1.2.1 Domain Specific Ontology Construction

When Methontology is compared to the seven-step method, steps 1,2,3,4,6 and 7 have already been covered in the top ontology. Therefore, for domain specific ontology the same definitions could be used as the beginning part of the

documentation. (Step 9) Additional conceptualization (Step 3) and formalization (Step 4) to include detailed information will be done in the next section.

Under TR equipment types all vocabulary have been indicated with their parameters. As it is indicated at Table 4.1, there are some parameters which will be reviewed by the contractor and consultant at the beginning of the coordination process, because as mentioned previously, BICSI and TIA gives several acceptable options for equipment properties or spatial requirements. Additionally, each project has its own building specifications and own ICT loads which will directly affect the quantities and selected products. Therefore, for a consistent coordination process, as it is represented as maintenance (Step 9) in Methontology, these rules should be reviewed and agreed to by all agents.

Furthermore, different disciplines may have varied equipment types, therefore their contribution from the beginning of the coordination process is crucial. For instance, the project mechanical specifications might include a mechanism for the controlled air conditioning in TR rooms such as VAV, or the electrical specifications might be requesting distribution panels to be located outside of the room. The agents who are responsible for the TR coordination could not initiate the coordination process without these decisions. In Table 4.2, the requirements of the TR building elements have been indicated again according to BICSI and TIA. During the material selection phase, these minimum requirements have to be considered. In this study, with the proposed top ontology and domain specific ontology, it has been aimed to define these rules at the beginning of the project.

Table 4.1 TR Equipment Types and their recommended constraints. (BICSI, 2020)

TR Equipment Types		
Rack Cabinet		Unit
Quantity	3	No
Width	800	mm
Depth	1200 or 800	mm
Height	2100	mm
FrontClearance	1000	mm
RearClearance	1000	mm
SideClearance	900	mm
HeightClearance	3000 or 3300	mm
Mounting	Self Stand	N/A
MountingHeightFromFFL	0	mm
Fan Coil Unit (FCU)		
Quantity	2	No
Width	600	mm
Depth	600	mm
Height	2200	mm
BaseHeight	285	mm
TotalHeight	2485	mm
FrontClearance	500	mm
RearClearance	50	mm
SideClearance	50	mm
Mounting	Self Stand	N/A
MountingHeightFromFFL	0	mm
Distribution Board (DB) Panel		
Quantity	2	No
Width	500	mm
Depth	115	mm
Height	1150	mm
FrontClearance	500	mm
RearClearance	0	mm
SideClearance	100	mm
Mounting	WallMounted	N/A
MountingHeightFromFFL	700	mm
Electrical Isolator (ISO)		
Quantity	2	No
Width	150	mm
Depth	100	mm
Height	200	mm
FrontClearance	500	mm
RearClearance	0	mm
SideClearance	50	mm

Table 4.1 Continued

Mounting	WallMounted	N/A
MountingHeightFromFFL	1300	mm
Other Accessories (Telephone, Lighting Switches, Thermostat,etc.)		
Quantity	1	No
Width	700	mm
Depth	50	mm
Height	700	mm
FrontClearance	500	mm
RearClearance	0	mm
SideClearance	50	mm
Mounting	WallMounted	N/A
MountingHeightFromFFL	1200	mm

Table 4.2 TR Room Building Elements and their recommended constraints.
(BICSI, 2020)

TR Building Elements		
Walls		Unit
FireRated	60	mins
FinishingMaterial	AntiDust	N/A
Floors		
FinishingMaterial	AntiDust and AntiStatic	N/A
Doors		
FireRated	60	mins
ClearWidth	915	mm
ClearHeight	2300	mm
OpeningDirection	Outside	N/A
OpeningAngle	90 / More than 90 / 180	N/A
Ceiling		
FalseCeiling	Not recommended	
FinishingMaterial	AntiDust	N/A
CeilingHeight	3000 or 3300	mm
Location		
RoomToRoomDistance	70	m
OverheadPiping	Not allowed	N/A
OverheadDuct	Not allowed/Should be discussed	N/A

These building elements and their constraints were directly related to architectural elements. Furthermore, the location criteria have to be taken into consideration

during the initial design phase of the projects. At the beginning of the project, having a defined rule set could eliminate reworks at the coordination period in different packages (wall, floor, door, etc.), and the contractor and client could consider the information related to the finishing materials at the tender period of the project because they have a direct impact on the cost.

Step 3.1. Domain specific ontology classes and their subclasses in natural language

For this ontology, five main classes have been defined for rooms, equipment types, building elements, constraints for TRs and outcomes of the SWRL rules. Class definitions have been determined as follows:

1. Rooms: This class includes all TRs in the project that need to comply with all required rules. Indicating rooms one by one as instances facilitates the coordination process and increases the manageability of constraint controls.

1.1. TRBuildingElementCompliantRooms: This class includes the compliant rooms according to the TRBuildingElement constraints.

1.2. BuildingElementIssues: This class includes the rooms with issues related to TRBuildingElement rule set. FireRatingIssues and MaterialIssues have been defined as its subclasses.

1.3. TREquipmentCompliantRooms: This class includes the compliant rooms according to the TREquipment constraints.

1.4. SpatialIssues: This class includes the rooms with issues related to TREquipment rule set. RoomLocationIssues, MountingHeightIssues and Clearance Issues have been indicated as its subclasses.

TRBuildingElements: This class includes building elements and their properties of TR rooms. Its subclasses include Walls, Floors, Doors, Ceiling and Location.

TREquipment: This class includes the equipment types and their spatial properties for TR rooms. Rack Cabinet, Fan Coil Unit (FCU), Distribution Board (DB) Panel,

Electrical Isolator (ISO) and other accessories (Telephone, Lighting, Switches, Thermostat, etc.) have defined subclasses this class.

Step 3.2 Relations between classes in natural language

- Rooms class has some equipment types from TREquipment.
- Rooms class has some elements from TRBuildingElements.
- SpatialIssues class is indicated by individuals from Rooms class that has some equipment constraint issues within.
- BuildingElementIssues class is indicated by individuals from Rooms class that has some building elements constraint issues within.

Step 3.3 Object properties of the relations

In this domain specific ontology, as it has been highlighted previously, the main aim is to record the data which has been retrieved from BICSI and TIA for coordination of TRs repetitively. Therefore, as it can be seen in Table 4.3, defined relations have the same domain class “Rooms”. The first group includes the has x – is x Of relationship between individual rooms to their types of equipment or their building elements. At the second group, the relations between rooms and named issues have been indicated. Range classes have been defined for each room after compliance audits which have been defined as subclass restrictions or SWRL rules. The implementation of the rules and constraints will be discussed in the following section.

Table 4.3 Object properties for domain specific ontology.

	Domain	Range	Object Property	Inverse Of
Group 1	Rooms	TRBuildingElements	hasBuildingElement	isBuildingElementOf
	Rooms	Doors	hasDoor	isDoorOf
	Rooms	Floors	hasFloor	isFloorOf
	Rooms	Walls	hasWall	isWallOf
	Rooms	TREquipment	hasEquipment	isEquipmentOf
	Rooms	DBPanel	hasDBPanel	isDBPanelOf
	Rooms	FanCoil	hasFanCoil	isFanCoilOf
	Rooms	RackCabinet	hasRackCabinet	isRackCabinetOf

Table 4.3 Continued

Group 2	Rooms	SpatialIssues	hasArealIssue	isIndicatedByArealIssueIn
	Rooms	ClearanceIssues	hasClearanceIssue	isIndicatedByClearanceIssueIn
	Rooms	FireRatingIssues	hasFireRatingIssue	isIndicatedByFireRatingIssueIn
	Rooms	RoomLocationIssues	hasLocationIssue	isIndicatedByLocationIssueIn
	Rooms	BuildingElementIssues	hasMaterialIssue	isIndicatedByMaterialIssueIn
	Rooms	MountingHeight	hasModelingIssue	isIndicatedByModelingIssueIn
	Rooms	RoomLocationIssues	hasPipingIssue	isIndicatedByPipingIssueIn

After defining classes and relations (object properties), for the construction of a domain-specific ontology for TRs, the data properties have been carefully created. These properties have been designed to provide detailed and accurate descriptions of each class within the ontology. Attributes such as front, rear, and side clearances have been defined to record the agreed equipment placement rules for compliance checks which need greater than or less than expressions defined in SWRL rules. Specific data properties such as door opening direction or fan coil front clearance have been indicated as parameters for each room, which allows the establishment of the exact value restrictions for subclasses. The precise definition of these data properties is crucial for effective compliance monitoring and for facilitating the coordination process of the TRs. Additionally, under Resources class (which has its naming from top-level ontology), the possible actions after identifying the non-compliance issues have been added as individuals. The utilization of these individuals with defined data properties has provided connection points with the other actions (such as Revision3D) defined in top-level ontology.

Table 4.4 Data properties for domain specific ontology.

Class	Data Property	Type
TREquipment	category	xsd:string
	width	xsd:integer
	depth	xsd:integer
	height	xsd:integer
	frontClearance	xsd:integer
	rearClearance	xsd:integer
	sideClearance	xsd:integer

Table 4.4 Continued

	mountingType	xsd:string
	mountingHeight	xsd:integer
TRBuilding Element	fireRating	xsd:integer
	clearHeight	xsd:integer
	clearWidth	xsd:integer
	openingDirection	xsd:string
	openingAngle	xsd:integer
	materialAntiDust	xsd:string
Rooms	roomArea	xsd:decimal
	roomWidth	xsd:decimal
	roomDepth	xsd:decimal
	roomToRoomDistance	xsd:integer
	numberOfRack	xsd:integer
	rackClusterFnRClearance	xsd:integer
	rackClusterSideClearance	xsd:integer
	numberOfFanCoil	xsd:integer
	fanCoilFrontClearance	xsd:integer
	dBPanelMountingHeight	xsd:integer
	overheadPiping	xsd:string
	doorOpeningDirection	xsd:string
	doorClearWidth	xsd:integer
	floorMaterialAntiDust	xsd:string
	wallMaterialAntiDust	xsd:string
	wallFireRating	xsd:integer

For the domain specific ontology for the TRs, samples for classes, their relations, object properties of the relations and data properties of the classes have been identified. Because the study has focused on coordination process of the TRs', related concepts have been derived from BICSI and TIA standards. The development process of the domain specific ontology has been recorded step by step for further expansion of the ontology according to necessities.

4.1.2.2 Domain Specific Ontology Semantic Model Representation

In the domain of TR coordination, the usage of the Web Ontology Language (OWL) has been critical for expressing the complex structure and interactions essential to TR management. This domain has encompassed crucial elements such as "Room Layout Design Constraints", "Equipment Constraints", and "Building Element Constraints" which have been integral to ensure the TR configurations complies with the established standards and stakeholder expectations. The following XML representation, which has been adapted to the domain-specific ontology, has leveraged capabilities of OWL to systematically encode the key components and processes ruling TR coordination. This structured representation has provided a computationally interpretable framework, thereby facilitated automated reasoning and optimization of the coordination process and ensured compliance with specified guidelines. This approach has not only demonstrated the effectiveness of the OWL in encapsulating complex domain-specific knowledge but also its significance in computational analysis and decision-making for TR coordination in airport projects.

A portion of domain specific ontology in XML format has been indicated as follows:

<!-- Class Definitions -->

`<owl:Class rdf:about="trspe:Rooms"/>`

`<owl:Class rdf:about="trspe:TREquipment"/>`

`<owl:Class rdf:about="trspe:TRBuildingElements"/>`

<!-- Object Properties -->

`<owl:ObjectProperty rdf:about="trspe:hasEquipment">`

`<rdfs:domain rdf:resource="trspe:Rooms"/>`

`<rdfs:range rdf:resource="trspe:TREquipment"/>`

```

</owl:ObjectProperty>

<owl:ObjectProperty rdf:about="trspe:hasBuildingElement">
    <rdfs:domain rdf:resource="trspe:Rooms"/>
    <rdfs:range rdf:resource="trspe:TRBuildingElements"/>
</owl:ObjectProperty>

<!-- Class Restrictions -->
<owl:Class rdf:about="trspe:Rooms">
    <rdfs:subClassOf>
        <owl:Restriction>
            <owl:onProperty rdf:resource="trspe:hasEquipment"/>
            <owl:someValuesFrom rdf:resource="trspe:TREquipment"/>
        </owl:Restriction>
    </rdfs:subClassOf>
    <rdfs:subClassOf>
        <owl:Restriction>
            <owl:onProperty rdf:resource="trspe:hasBuildingElement"/>
            <owl:someValuesFrom
                rdf:resource="trspe:TRBuildingElements"/>
        </owl:Restriction>
    </rdfs:subClassOf>
</owl:Class>

```

4.1.2.3 Domain Specific Ontology Semantic Rule Modeling

In the complex domain of TR coordination, ensuring compliance with standards and related specifications is essential for operational efficiency and safety of the airports. To overcome this difficulty, the SWRL has been incorporated into the domain-specific ontology. The expressive power of SWRL has enabled the linkage of critical rules that automatically inferred compliance/non-compliance statuses within TR configurations based on a comprehensive set of criteria. This section presents a set of SWRL rules designed to evaluate critical aspects of TRs which were explained in detail under previous sections. These rules aim to serve as an automated reasoning mechanism, facilitating the identification of discrepancies and potential issues in TR designs. By integrating these rules into the domain specific ontology, the capability has been obtained not only to represent but also to actively analyze and validate the alignments of TR configurations with predefined requirements. This approach aims to simplify the coordination process and strengthen conformity to critical standards.

Rule 1. *Rooms(?r) ^ roomToRoomDistance(?r, ?d) ^ swrlb:greaterThan(?d, 70) -> RoomLocationIssues(?r) ^ hasLocationIssue(?r, RequiresRoomRelocationMeeting)*
This rule identifies the rooms which has room to room distance more than 70 m, which is not allowed in defined rule set and leads the room coordination to room relocation meeting.

Rule 2. *Rooms(?r) ^ roomArea(?r, ?a) ^ swrlb:lessThan(?a, 12) ->*

hasAreaIssue(?r, MayRequireRoomEnlargementMeeting) ^ SpatialIssues(?r)

This rule checks the room area values and highlights the rooms which have a smaller area than 12 sqm. Additionally, it indicates the next possible step as “may require room enlargement meeting”, if this small sqm causes a problem in room layout.

Rule 3. *Rooms(?r) ^ overheadPiping(?r, "Yes"^^xsd:string) -> RoomLocationIssues(?r) ^ hasPipingIssue(?r, RequiresRoomRelocationMeeting)*

This rule is for controlling whether there is a piping infrastructure passing over TR or not. If there is, the room is to be marked as “has piping issue” and the next step is to be defined as “requires room relocation meeting”.

Rule 4. *Rooms(?r) ^ rackClusterFnRClearance(?r, ?c) ^ swrlb:lessThan(?c, 1000) -> hasClearanceIssue(?r, MayRequireRoomEnlargementMeeting) ^ ClearanceIssues(?r)*

This rule identifies the rooms which do not comply with required front and rear clearance rules for rack cabinets, then indicates it as an individual under the class “Clearance Issues” and defines a next step “may require room enlargement meeting”.

Rule 5. *Rooms(?r) ^ dBPanelMountingHeight(?r, ?h) ^ swrlb:lessThan(?h, 700) -> MountingHeight(?r) ^ hasModelingIssue(?r, RequiresModelRevision)*

This rule identifies the rooms that include different mounting height for DB panels than defined in the rule set and indicates that room requires model revision.

Rule 6. *Rooms(?r) ^ doorOpeningDirection(?r, "Inward") -> FireRatingIssues(?r) ^ hasFireRatingIssue(?r, RequiresModelInformationRevision)*

This rule identifies the rooms that have inward opening door(s), which is not allowed according to fire safety rules, and then indicates that room requires model information revision.

Rule 7. *Rooms(?r) ^ wallFireRating(?r, ?fr) ^ swrlb:lessThan(?fr, 60) -> FireRatingIssues(?r) ^ hasFireRatingIssue(?r, RequiresModelInformationRevision)*

This rule aims to identify rooms with less fire rating value walls than required and marks them as “requires model information revision”.

4.2 Ontology Implementation and Validation

Protégé 5.6.3 platform has been utilized for implementation and validation of the two defined ontologies. As explained widely in previous sections, for both top-level

(trcoor) and domain specific (trspeg) ontologies; classes and their restrictions, object properties and their domains/ranges, and data properties have been implemented in Protégé. For creating instances to validate the ontologies, Cellfie plug-in has been used for quick information translation into ontologies. Under the following headings, screenshots from implementation processes have been indicated.

4.2.1 Top-Level Ontology Construction

The overall class, object property and data property hierarchies for top-level ontology have been indicated at the upper half of Figure 4.2. At the below half, defined class restrictions and the usage of “Evaluate2DActivity” class has been presented as an example. From object properties, “isEvaluatedBy” has been illustrated with its inverse “evaluates” and from data properties “submissionStatus” has been highlighted with its range type “xsd:string”. These implementations have been similarly done for all elements.

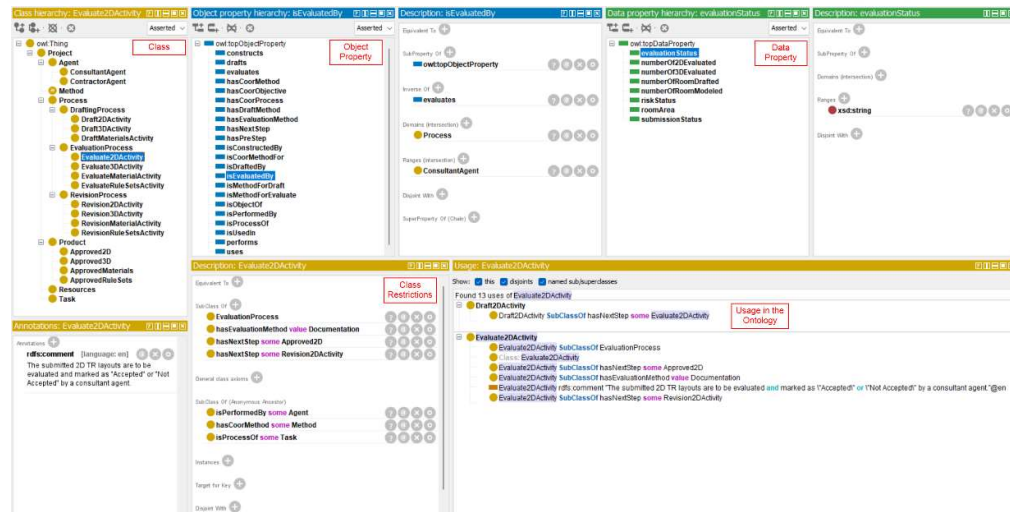


Figure 4.1 Constructed top-level ontology in Protégé 5.6.3.

As mentioned in the seven-step method, for validation of the ontology, creating instances is a crucial step. The automatic instance classifications according to their object and data properties is the main aim of this top-level ontology to record the

process of the TR coordination. To be able to experience that, TREquipment, TRBuildingElement and 15 TR rooms' 2D draft and 3D model versions have been implemented in ontology. In Figure 4.3, under “Process” general class, 2D_TR1001 instance has been indicated with its defined object properties and data properties.

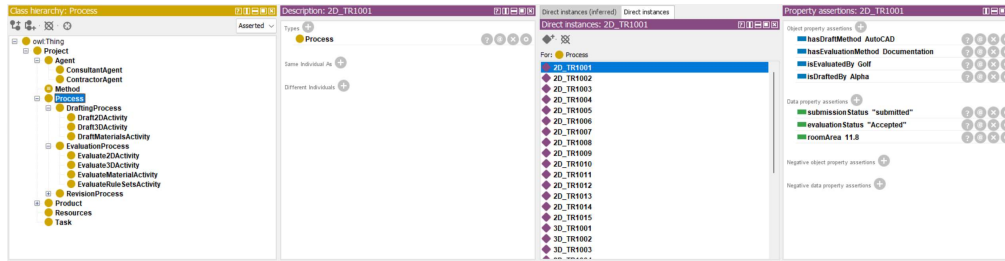


Figure 4.2 Instance creation in Protégé for top-level ontology.

After implementing all, the Pellet reasoner in Protégé was run to identify if there are any inconsistencies in the ontology to be fixed. Class, object, data hierarchies, their assertions and individuals in the ontology have been checked as it is indicated in Figure 4.4, and no inconsistencies were found. Additionally, as it is indicated in Figure 4.5, OntoDebug has reviewed 508 axioms which were created for top-level ontology and the ontology has passed the incoherency and inconsistency test.

```
----- Running Reasoner -----
Pre-computing inferences:
- class hierarchy
- object property hierarchy
- data property hierarchy
- class assertions
- object property assertions
- data property assertions
- same individuals
Ontologies processed in 560 ms by Pellet
```

Figure 4.3 The Pellet reasoner result.



Figure 4.4 The result of OntoDebug.

As described earlier, to enrich the class relations and the knowledge representation in the ontology, the study has drawn from SWRL features. The defined rules for top-level ontology, which aim to categorize TR layouts according to their document status to be able to handle by assigned agent class and to include a warning for possible layout problems, has been implemented. After synchronizing the reasoner, SWRL rules have been added required is-a relations between individuals and classes. In Figure 4.7, the inferred individuals for “Approved 2D” class has been indicated. As seen, if a room’s 2D layout has been submitted and evaluated as accepted, this instance is also a member of Process, Evaluate2DActivity and Approved2D classes.

Name	Rule	Comment
Rule 01	<code>trcoor:Process(?p) ^ trcoor:submissionStatus(?p, "workInProgress"^^rdf:PlainLiteral) ^ trcoor:hasDraftMethod(?p, trcoor:AutoCAD) -> trcoor:Draft2DActivity(?p)</code>	ActivitySequence_1_2D
Rule 02	<code>trcoor:Process(?p) ^ trcoor:submissionStatus(?p, "submitted"^^rdf:PlainLiteral) ^ trcoor:hasDraftMethod(?p, trcoor:AutoCAD) -> trcoor:Evaluate2DActivity(?p)</code>	ActivitySequence_2_2D
Rule 03	<code>trcoor:evaluationStatus(?p, "Accepted"^^rdf:PlainLiteral) ^ trcoor:Evaluate2DActivity(?p) ^ trcoor:hasEvaluationMethod(?p, trcoor:Documentation) -> trcoor:Approved2D(?p)</code>	ActivitySequence_3_2D
Rule 04	<code>trcoor:evaluationStatus(?p, "Not Accepted"^^rdf:PlainLiteral) ^ trcoor:Evaluate2DActivity(?p) ^ trcoor:hasEvaluationMethod(?p, trcoor:Documentation) -> trcoor:Revision2DActivity(?p)</code>	ActivitySequence_4_2D
Rule 05	<code>trcoor:Process(?p) ^ trcoor:submissionStatus(?p, "workInProgress"^^rdf:PlainLiteral) ^ trcoor:hasDraftMethod(?p, trcoor:Revit) -> trcoor:Draft3DActivity(?p)</code>	ActivitySequence_1_3D
Rule 06	<code>trcoor:Process(?p) ^ trcoor:submissionStatus(?p, "submitted"^^rdf:PlainLiteral) ^ trcoor:hasDraftMethod(?p, trcoor:Revit) -> trcoor:Evaluate3DActivity(?p)</code>	ActivitySequence_2_3D
Rule 07	<code>trcoor:evaluationStatus(?p, "Accepted"^^rdf:PlainLiteral) ^ trcoor:Evaluate3DActivity(?p) ^ trcoor:hasEvaluationMethod(?p, trcoor:Navisworks) -> trcoor:Approved3D(?p)</code>	ActivitySequence_3_3D
Rule 08	<code>trcoor:evaluationStatus(?p, "Not Accepted"^^rdf:PlainLiteral) ^ trcoor:Evaluate3DActivity(?p) ^ trcoor:hasDraftMethod(?p, trcoor:Revit) -> trcoor:Revision3DActivity(?p)</code>	ActivitySequence_4_3D
Rule 09	<code>trcoor:Process(?p) ^ trcoor:submissionStatus(?p, "submitted"^^rdf:PlainLiteral) ^ trcoor:hasEvaluationMethod(?p, trcoor:Meeting) -> trcoor:ApprovedRuleSets(?p)</code>	Initial Activity
Rule 10	<code>trcoor:Process(?p) ^ trcoor:submissionStatus(?p, "submitted"^^rdf:PlainLiteral) ^ trcoor:hasEvaluationMethod(?p, trcoor:Meeting) -> trcoor:EvaluateRuleSetsActivity(?p)</code>	Initial Activity
Rule 11	<code>trcoor:Process(?p) ^ trcoor:evaluationStatus(?p, "Accepted"^^rdf:PlainLiteral) ^ trcoor:hasEvaluationMethod(?p, trcoor:Meeting) -> trcoor:Resources(?p)</code>	Initial Activity
Rule 12	<code>trcoor:Process(?p) ^ trcoor:roomArea(?p, ?ra) ^ swrl:lessThan(?ra, 12) -> trcoor:riskStatus(?p, "High"^^rdf:PlainLiteral)</code>	RiskAssessment

Figure 4.5 SWRL rules implemented in Protégé.

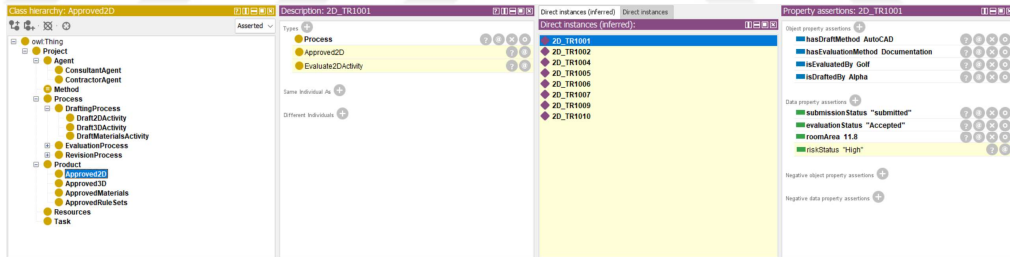


Figure 4.6 Inferred instances after synchronizing the reasoner with SWRL rules.

In Protégé, there are several visualization plug-ins for creating ontology graphs such as OWLViz and OntoGraf. However, due to being a responsive web application which visualizes the rdf or owl file in any computer, WebVOWL has been selected for the demonstration of the ontology. In Figure 4.8, the object properties between classes have been indicated with solid lines, and the class hierarchy with dashed lines. The data properties and their data types have been illustrated with their domain classes.

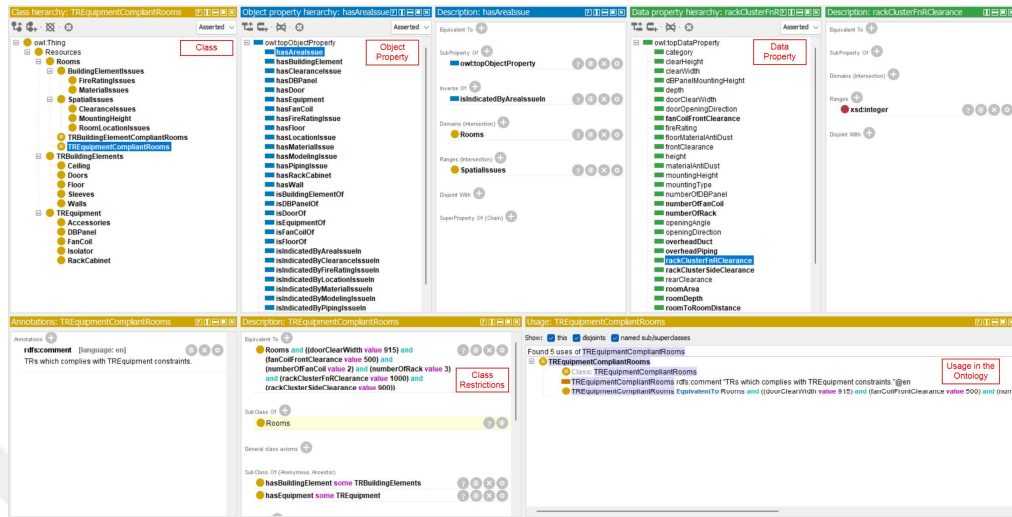


Figure 4.8 Constructed domain specific ontology in Protégé 5.6.3.

For the validation step, related instances have been created to track the path of the rooms during the coordination process. In Figure 4.10, sample instance “TR_1001” has been illustrated with its object and data properties. These parameters will be utilized for the classification of the TRs according to agreed constraints.

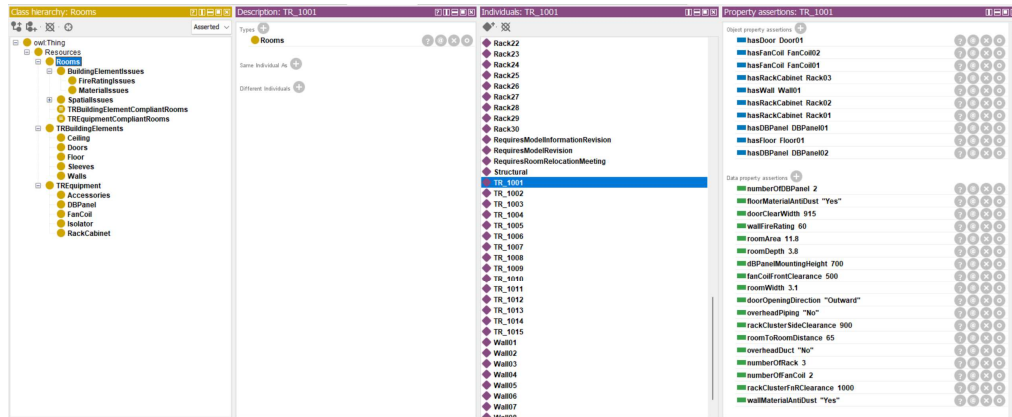


Figure 4.9 Instance creation in Protégé for domain specific ontology.

Pellet reasoner result has been received as consistent for domain specific ontology and OntoDebug outcome observed as coherent and consistent after checking 1497 axioms which were implemented in Protégé.

```

----- Running Reasoner -----
Pre-computing inferences:
  - class hierarchy
  - object property hierarchy
  - data property hierarchy
  - class assertions
  - object property assertions
  - data property assertions
  - same individuals
Ontologies processed in 130 ms by Pellet

```

Figure 4.10 The Pellet reasoner result for domain specific ontology.



Figure 4.11 The result of OntoDebug for domain specific ontology.

The remaining constraints, after using the class restriction features in Protégé, have been projected in the ontology construction by utilizing SWRL. In Figure 4.13, implemented rules have been indicated. Right after synchronizing the reasoner, equivalent classes and missing object properties have been completed by Protégé. As observed in Figure 4.14, TR_1001 additionally has been a member of the Spatial Issues, TR Building Element Compliant Rooms, and TR Equipment Compliant Rooms. It should be noted that being a member of the “Spatial Issues” does not directly mean there is a problem, but it marks the room as there might be a problem for the drafting agent. Next, in Figure 4.15, the visualization of the domain specific ontology is represented without data properties for clear graphic representation by WebVOWL.

Name	Rule	Comment
Rule 1	<code>swrlb:greaterThan(?d, 70) ^ trspe:roomToRoomDistance(?r, ?d) ^ trspe:Rooms(?r) -> trspe:RoomLocationIssues(?r) ^ trspe:hasLocationIssue(?r, trspe:RequiresRoomRelocationMeeting)</code>	RoomLocationIssue
Rule 2	<code>trspe:Rooms(?r) ^ trspe:roomArea(?r, ?a) ^ swrlb:lessThan(?a, 12) -> trspe:hasAreaIssue(?r, trspe:MayRequireRoomEnlargementMeeting) ^ trspe:SpatialIssues(?r)</code>	Area Issue
Rule 3	<code>trspe:overheadPiping(?r, "Yes"^^rdf:PlainLiteral) ^ trspe:Rooms(?r) -> trspe:RoomLocationIssues(?r) ^ trspe:hasPipingIssue(?r, trspe:RequiresRoomRelocationMeeting)</code>	RoomPipingIssue
Rule 4	<code>trspe:Rooms(?r) ^ trspe:rackClusterFrRClearance(?r, ?c) ^ swrlb:lessThan(?c, 1000) -> trspe:hasClearanceIssue(?r, trspe:MayRequireRoomEnlargementMeeting) ^ trspe:ClearanceIssues(?r)</code>	ClearanceIssue
Rule 5	<code>trspe:Rooms(?r) ^ swrlb:lessThan(?h, 200) ^ trspe:dPanelMountingHeight(?r, ?h) -> trspe:hasModelingIssue(?r, trspe:RequiresModelRevision)</code>	ModelingMistake
Rule 6	<code>trspe:Rooms(?r) ^ trspe:doorOpeningDirection(?r, "Inward"^^rdf:PlainLiteral) -> trspe:FireRatingIssues(?r) ^ trspe:hasFireRatingIssue(?r, trspe:RequiresModelInformationRevision)</code>	FireRatingIssue2
Rule 7	<code>trspe:Rooms(?r) ^ trspe:wallFireRating(?r, ?fr) ^ swrlb:lessThan(?fr, 60) -> trspe:FireRatingIssues(?r) ^ trspe:hasFireRatingIssue(?r, trspe:RequiresModelInformationRevision)</code>	FireRatingIssue

Figure 4.12 SWRL rules implementation in domain specific ontology.

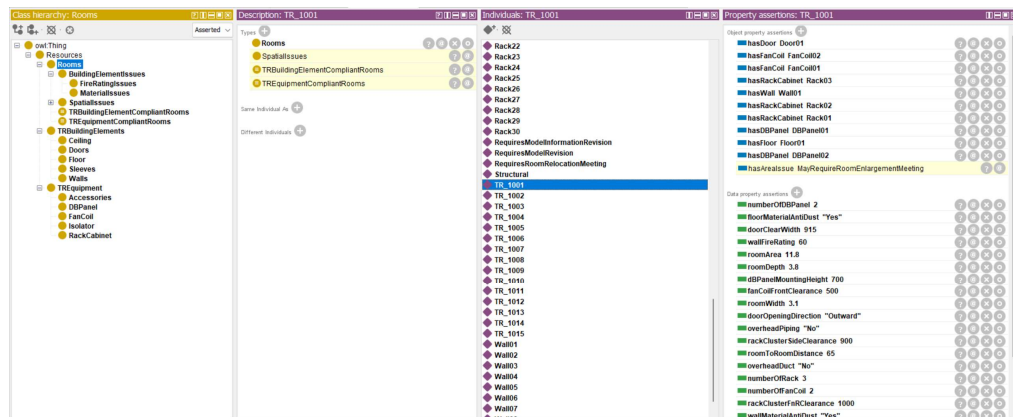


Figure 4.13 Inferred instances after synchronizing the reasoner with SWRL rules.

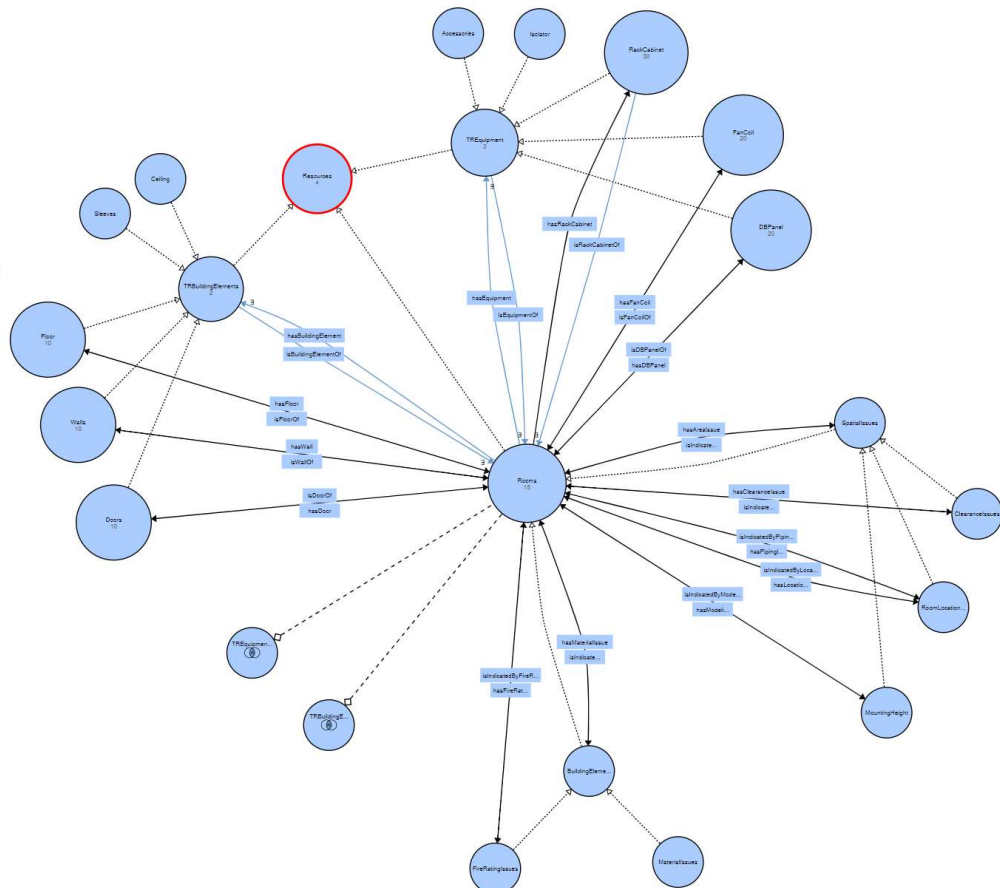


Figure 4.14 The visualization of the domain-specific ontology by WebVOWL.

4.2.3 Results from Test Case

As it is indicated in previous sections, for the validation, the individual creation is a crucial process to test the operability of the constructed ontologies. In this study, for testing both ontologies, 15 telecommunication rooms have been entered with their required information.

For the top-level ontology, because the main aim is to record the process steps both in 2D and 3D, two methods have been reflected to the naming of the individuals, as done in documentations in construction processes. More importantly, `TREquipment` and `TRBuildingElements` individuals have been created to represent the pre-defined rule sets which have been reviewed, revised (if necessary) and approved at the beginning. These two individuals should become products of this top-level ontology to initiate the TR coordination process and it should also be located under Resource class.

For 2D and 3D documents of each TR, related object and data properties have been implemented to test the categorization according to defined framework. As indicated in Figure 4.16, to categorize process location of each individual, `submissionStatus` and `evaluationStatus` data properties have been implemented. By using SWRL rules, “notStated” ones only stayed in process class, rest of the documentation has been categorized under related process subclasses such as `DraftProcess` or `EvaluateProcess`. Additionally, the `roomArea` data property has been used to indicate the risk status of each TR as a warning for agent before commencing the draft process. For each room individual the data property “`riskStatus`” have been filled by using defined SWRL rule. If the area is smaller than the optimum value, it has been noted as high risk.

Simultaneously, with the help of the defined class restrictions which used object properties like `hasDraftMethod` or `hasEvaluationMethod`, the individuals moved in `Draft2DActivity` or `Evaluate3DActivity` according to their defined object property values. The inferred individual locations under subclasses resulted as indicated in

Figure 4.17. Finally, to check the consistency of the class-to-class relations with their individuals, five consultant agents and five contractor agents have been defined. TR individuals have been connected to related agents with “isDraftedBy” or “isEvaluatedBy” relationships and thanks to inverse of description for both of the object properties, agent individuals have also filled with assigned TR individuals as indicated in Figure 4.18.

Drafts	room Area	risk Status	submission Status	evaluation Status	is Drafted By	is Evaluated By	hasDraft Method	hasEvaluation Method
TREquipment			submitted	Accepted		Foxtrot	Meeting	Meeting
TRBuildingElements			submitted	Accepted		Foxtrot	Meeting	Meeting
2D_TR1001	11.8		submitted	Accepted	Alpha	Golf	AutoCAD	Documentation
2D_TR1002	13.5		submitted	Accepted	Bravo	Golf	AutoCAD	Documentation
2D_TR1003	15		submitted	Not Accepted	Charlie	Hotel	AutoCAD	Documentation
2D_TR1004	16.8		submitted	Accepted	Delta	Hotel	AutoCAD	Documentation
2D_TR1005	18		submitted	Accepted	Echo	India	AutoCAD	Documentation
2D_TR1006	10.5		submitted	Accepted	Alpha	India	AutoCAD	Documentation
2D_TR1007	12.5		submitted	Accepted	Alpha	Juliet	AutoCAD	Documentation
2D_TR1008	11.2		submitted	Not Accepted	Bravo	Juliet	AutoCAD	Documentation
2D_TR1009	13.4		submitted	Accepted	Bravo	Juliet	AutoCAD	Documentation
2D_TR1010	14.5		submitted	Accepted	Charlie	Foxtrot	AutoCAD	Documentation
2D_TR1011	11.5		workInProgress		Delta		AutoCAD	Documentation
2D_TR1012	13.6		workInProgress		Echo		AutoCAD	Documentation
2D_TR1013	14.5		workInProgress		Alpha		AutoCAD	Documentation
2D_TR1014	12.8		workInProgress		Alpha		AutoCAD	Documentation
2D_TR1015	10.3		workInProgress		Charlie		AutoCAD	Documentation
3D_TR1001	11.8		submitted	Accepted	Alpha	Foxtrot	Revit	Navisworks
3D_TR1002	13.5		submitted	Accepted	Bravo	Foxtrot	Revit	Navisworks
3D_TR1003	15		workInProgress		Charlie		Revit	Navisworks
3D_TR1004	16.8		submitted	Not Accepted	Delta	Golf	Revit	Navisworks
3D_TR1005	18		submitted	Not Accepted	Echo	Hotel	Revit	Navisworks
3D_TR1006	10.5		submitted	Accepted	Alpha	India	Revit	Navisworks
3D_TR1007	12.5		submitted	Accepted	Alpha	Juliet	Revit	Navisworks
3D_TR1008	11.2		workInProgress		Bravo		Revit	Navisworks
3D_TR1009	13.4		workInProgress		Bravo		Revit	Navisworks
3D_TR1010	14.5		workInProgress		Charlie		Revit	Navisworks
3D_TR1011	11.5		notStarted				Revit	Navisworks
3D_TR1012	13.6		notStarted				Revit	Navisworks
3D_TR1013	14.5		notStarted				Revit	Navisworks
3D_TR1014	12.8		notStarted				Revit	Navisworks
3D_TR1015	10.3		notStarted				Revit	Navisworks

Figure 4.15 Individual inputs for test case.

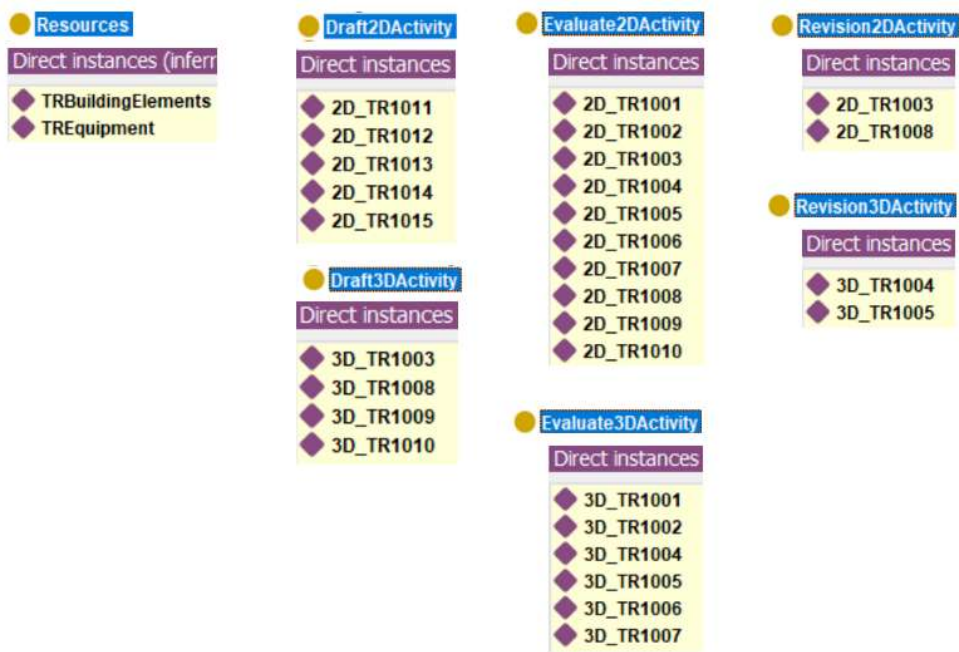


Figure 4.16 Inferred individuals under subclasses.



Figure 4.17 Examples from inferred object properties for agents.

For the domain specific ontology, the main aim is to review the rooms according to the agreed rule sets (TREquipment and TRBuildingElements) and classify the rooms

according to their compliance or incompliance. Therefore, 10 of 15 rooms have been implemented in detail with their data properties because their coordination process has been initiated. First of all, according to the agreed rule set equipment instances have been created. Rack01, Rack02 or FanCoil01, FanCoil02 have been indicated as individuals to be able to check the room elements. Therefore, equipment type instances have been connected to room individuals directly with related object properties. For instance, again by using the inverse of facility under object properties section, after defining rooms with equipment types included, the equipment instances could express the location information by using “isEquipmentOf” property. To reach the compliance classification aim, first class restrictions have been utilized for numeric values. Then, defined data property values have been used for comprising the agreed values with existing model or layout values. For categorizing noncompliant classes, SWRL rules have been used. In Figure 4.19, the classification of rooms has been indicated after the ontology reasoning.

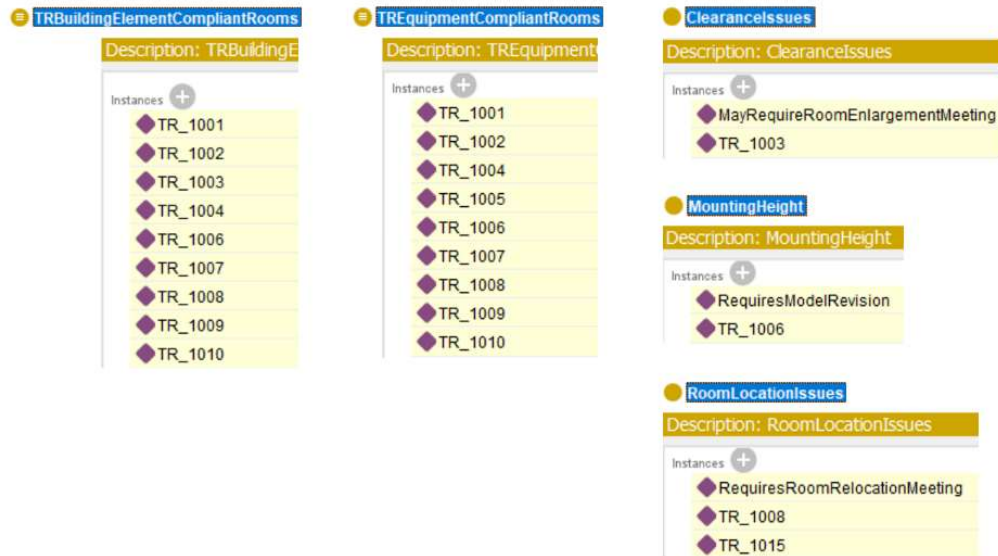


Figure 4.18 Classifications after restrictions and SWRL rules in domain specific ontology.

As understood from Figure 4.19, 4.20 and 4.21, there is one room (TR_1005) which is non-compliant according to the TRBuildingElements rule set and there is another room (TR_1003) that is incompliant with TREquipment rule set. For the non-compliance, as could be observed from screenshots, the next coordination step (method) has been also indicated by SWRL rules.

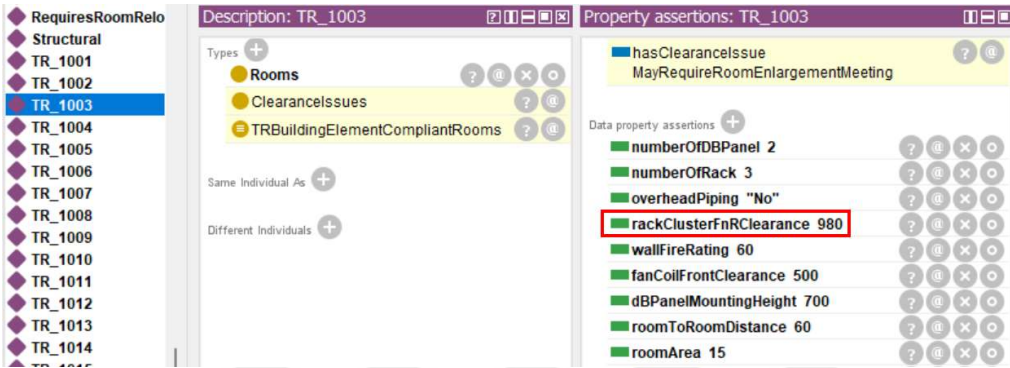


Figure 4.19 Non-compliance of TR_1003.



Figure 4.20 Non-compliance of TR_1005.

CHAPTER 5

CONCLUSION

This chapter presents a summary of the study, providing a brief overview of the research. Subsequently, it discusses the major outcomes and offers suggestions for future studies.

5.1 Research Summary

This thesis has focused on the utilization of ontologies for improving the coordination of telecommunication rooms in BIM-based airport projects. Initially, the evolution of airports and their operations were explored in the literature review (Chapter 2) and highlighted the complexity of this building type and the effects of increasing number of passengers on the building itself and its systems. Edwards (2005) highlighted that when it is necessary for an airport to expand, this means that more passenger facilities have to be provided. Likewise, IATA has frequently mentioned in their reports that passenger connection times remained as one of the most important constraints in airport design. Thus, to achieve the recommended time intervals and ensure passenger comfort, both the building and its systems have to be designed by taking potential future changes into consideration. These points have revealed that airport architecture itself has an interchangeable nature, therefore the parameterized design for building systems could ease the coordination process.

The improvements in the digitalization field have opened new doors to deal with the increasing demands in the aviation sector. Many studies have been conducted recording and examining the digital transformation in airports, and the studies of Alici (2023) and Fattah et al. (2009) could be cited as prominent examples. Fattah et

al. (2009) presented an overview of airport generations with passenger behavior and operation perspectives to explain the gap filled by digitalization creating smart airports. In the study conducted by Alici (2023), September 11th incident in the U.S. and the Covid-19 pandemic were identified as major catalysts in accelerating the digital transformation. The transformation was exemplified and guided by IATA (2018) and Airports Council International (2017) reports. These transformations have uncovered the importance of properly structured cabling systems. In the ACI (2017) report, the digitalization of airports was directly associated with the digitalization of the business model which has led the industry to think about the whole journey. For this reason, today the aviation industry is focused on the transformation in airport management to make “single token journey” possible for passengers. On the other hand, IATA (2018) emphasized the importance of strong and efficient cabling infrastructure and digitalization in airports, reminding that changes in data transparency and geopolitical environment can result in different needs, therefore the structured cabling infrastructure of airports should be designed flexibly for possible scenarios. In addition, IATA's New Aviation Ecosystem Roadmap (2023) emphasized that new aircraft technologies will emerge in the next 20 years, bringing transformations and revisions to standards, airspace structure, airport infrastructure, and ground/airport operations. Structured cabling systems will play a vital role in accommodating all these future revisions.

In Chapter 2, ICT infrastructure in airports has been introduced with all its elements. The system elements (entrance facility, main and secondary equipment rooms, telecommunication rooms, work area, and horizontal/vertical cabling) and their roles defined by BICSI and TIA standards were presented. BICSI and TIA manuals constitute the fundamental standards for architects and engineers responsible for ICT coordination in airport buildings and include implicit recommendations for the design of ICT infrastructure and required spaces. This thesis has focused on the smallest repetitive rooms which are built in several locations in airports for proper horizontal cable distribution for ICT's structural cabling system. Since the identifying of the types of equipment and their required quantities, and types of

building elements is crucial for the coordination of the ICT infrastructure, the recommendations, and constraints in BICSI and TIA have been utilized in this paper.

Next, the TR coordination challenges in BIM-based projects have been reviewed. Because the rules for reaching the fully coordinated TRs generally involve the equipment clearances or building elements' property information, the automated checking systems in BIM could not resolve issues directly. The coordination of TRs requires special coordination meetings for both defining and agreeing on the constraints and then implementing them on 2D layouts and 3D models as Korman et al. (2003) underlined the need for expert knowledge to solve the coordination problems. However, as Pogorelskiy and Kocsis (2022) mentioned in their studies, especially for special areas, leveraging BIM systems is crucial for necessary levels of precision and TRs are examples of these special technical spaces. Mehrbod (2019) has supported previous authors and identified three steps for BIM-based design coordination, which are (1) issue identification; (2) issue resolution; and (3) issue documentation. Overall, TRs are specific technical areas which require special attention for their coordination even in BIM-based projects, therefore not only the requirements for rooms but also the coordination steps have to focus on proper coordination of the ICT cabling systems. Therefore, to be able to record and reuse the knowledge and information, which is hidden in specifications and in experiences, two branches of information flow were studied for the development of this thesis paper. The first branch was the expression of the rules inside the specifications for TRs, and the second branch included the coordination steps of the TRs in BIM-based airport projects.

Further along the literature review, ontologies, along with their benefits and limitations, were discussed. The review demonstrated that ontologies support decision-making by structuring data in a way that is easily accessible and interpretable, allowing for quicker and more accurate decisions. (Hatcher, 2016) This is particularly important in airport projects, where decisions need to be made quickly to meet tight schedules and budget constraints. The ontological structure provides a

holistic view of project data, enabling stakeholders to make informed decisions that align with project goals and compliance requirements. (IATA, 2019)

In addition, the literature revealed that early integration of ontologies into project planning and execution phases demonstrate potential reductions in both the duration and the financial outlay of airport construction projects. By preventing delays and reducing the need for subsequent revisions, the project timeline can be shortened, leading to cost savings. (Alici, 2023) Furthermore, the efficient data management provided by ontologies minimizes the resources required for data handling and storage, as observed in practices endorsed by BICSI and TIA standards.

5.2 Research Contribution

The findings of this thesis have potential implications for the construction industry, particularly in the design and execution of airport projects. The adoption of pre-defined ontologies in the coordination of Telecommunications Rooms (TRs) offers a structured approach to managing complex information, which is critical in large-scale construction projects like airports. These ontologies can be implemented across different facets of project management, from design and engineering to operations management.

The clarity and standardization provided by ontologies allow architects and engineers to focus on the more creative aspects of design and problem-solving. With pre-defined ontologies, technical details regarding TR specifications, integration requirements, and compliance standards are clearly outlined, reducing ambiguity and the potential for design errors. This leads to more efficient design processes, where modifications are minimized, and productivity is enhanced. Furthermore, the use of ontologies supports a more collaborative approach, facilitating easier and more effective interdisciplinary communication, which is crucial in complex projects involving multiple engineering disciplines.

Project managers benefit from the use of ontologies through enhanced project tracking and management capabilities. Ontologies facilitate a better understanding of project milestones, deliverables, and dependencies, allowing for more precise scheduling and resource allocation. The clear structure of project data also aids in risk management by highlighting potential issues early in the project lifecycle, enabling proactive measures rather than reactive solutions. This capability is vital in managing the high stakes and tight schedules typical of airport construction projects.

Construction firms can achieve significant cost efficiencies by reducing the time spent on coordination and communication. The standardized data format provided by ontologies minimizes the time required to onboard new project members, allowing for smoother transitions and continuity in project teams. Additionally, the improved accuracy in project documentation reduces the likelihood of costly rework due to misunderstandings or miscommunications about technical requirements.

The findings of this thesis could influence how regulatory bodies and standards organizations view and implement standards across the industry. By demonstrating the efficacy of ontologies in improving compliance and efficiency, there may be a push towards broader adoption of ontology-based standards in construction project management, particularly for projects as critical as airports.

5.3 Limitations and Future Works

The main limitation of the findings of this thesis study is due to its scope. The scope was focused on the TRs within airport projects, which does not reflect the complexities of the airport construction comprehensively. However, future research could productively expand the use of ontologies within the construction industry as extending the application of ontologies beyond TRs to other aspects of airport construction could offer more comprehensive benefits. In addition, comparative studies assessing the effectiveness of ontology-based methods against traditional methods could further validate the advantages observed in this research.

Another limitation worth discussing comes from the nature of ontology-based coordination. Changing standard operating procedures to incorporate a new technology like ontologies involves significant shifts in current practices, which can result in resistance. Commitment, time and effort by the companies and teams will be necessary to overcome learning curves and adaptation barriers, which may be a roadblock in widespread implementation of ontologies. Additionally, the success of ontology applications heavily depends on the accuracy and completeness of the input data. In the dynamic environment of construction, where changes are frequent, maintaining this accuracy is a continuous challenge.

In addition to studying the application of ontologies in different sections of airport design, future research could potentially focus on the integration of advanced technologies like artificial intelligence and machine learning with ontologies. This integration could enhance ontology's predictive capabilities and automation, potentially revolutionizing project management practices. Lastly, implementing this approach in real-world projects and conducting longitudinal studies would provide valuable insights into its practical impacts and help refine the approach based on empirical evidence.

In conclusion, this thesis has established that pre-defined ontologies can significantly improve the coordination of telecommunications rooms within BIM-based airport projects, leading to enhanced efficiency, reduced costs, and better collaboration among stakeholders. The study contributes to the ongoing digitization and optimization of construction processes, aligning with the technological advancements and increasing demands of modern infrastructure development. As construction projects continue to increase in complexity and scale, the role of effective data management and communication becomes ever more critical. Ontologies, with their structured approach to data and process management, offer a promising tool to meet these challenges, providing a robust foundation for future innovations in construction project management.

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APPENDICES

A. Ethical Committee Approval

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MIDDLE EAST TECHNICAL UNIVERSITY

Konu: Değerlendirme Sonucu

18 OCAK 2024

Gönderen: ODTÜ İnsan Araştırmaları Etik Kurulu (İAEK)

İlgi: İnsan Araştırmaları Etik Kurulu Başvurusu

Sayın Mehmet Koray Pekerçiçi

Danışmanlığımı yürüttüğünüz Karya Bayır'ın "*BIM Tabanlı Havalimanı Projelerinde Önceden Tanımlanmış Ontolojiler ile Telekomünikasyon Odalarının Etkin Koordinasyonu*" başlıklı araştırmanız İnsan Araştırmaları Etik Kurulu tarafından uygun görülerek 0212-ODTÜİAEK-2024 protokol numarası ile onaylanmıştır

Bilgilerinize saygılarımla sunarım.

B. Survey Questions

Dear Sir or Madam,

First of all, thank you for your time in contributing to this study. You will see a survey in the following pages which is to be used in a thesis study in Building Science in Architecture at the Middle East Technical University, “Efficient Coordination of Telecommunications Rooms in Bim-Based Airport Projects Through Pre-Defined Ontologies”.

This study has been conducted by Karya Bayır under the supervision of Assoc. Prof. Dr. Mehmet Koray Pekerçli. This survey has been prepared for the architects and engineers in the airport construction industry. The gathered data will be used only for the analysis and the results will be discussed in the study without sharing any personal and company information.

The aim of the research is to investigate whether establishing a framework for the coordination process of telecommunication rooms at airports, which can be shared by relevant teams (designers, consultants, or contractors), would be beneficial for initiating the project in its early stages.

Karya Bayır

Architect / METU Department of Architecture M.Sc. Student

1. General information about you and your company (confidential)

Your Name/Surname:

Position:

Email:

Company Name:

Project Name:

2. Please select your company's role from below.

☐ Client

☐ Contractor

☐ Consultant

☐ Subcontractor

3. Number of employees in your company for this project.

☐ 1-10

☐ 21-50

☐ 11-20

☐ Over 50

4. Number of employees in your department (or related package) for this project.

☐ Only 1

☐ 11-20

☐ 2-5

☐ Over 20

☐ 6-10

5. In which stage your company has been approved for the aforementioned role?

☐ Concept Design Phase

☐ Shop Drawing Phase

☐ Design Drawing Phase

☐ Construction Phase

6. Could you please mark in which phases you communicated with which project stakeholders?

	Concept Design Phase	Design Drawing Phase	Shop Drawing Phase	Construction Phase
Client	☐	☐	☐	☐
Consultant	☐	☐	☐	☐
Contractor	☐	☐	☐	☐
Subcontractor	☐	☐	☐	☐
End-user	☐	☐	☐	☐

7. In which project phase your company started to use Building Information Modeling (BIM)?

- ☐ Concept Design Phase
 ☐ Shop Drawing Phase
☐ Design Drawing Phase
 ☐ Construction Phase

8. Could you please mark which techniques you used with project stakeholders to define the rule sets for the coordination of TR Rooms?

	Meetings	Workshops	2D Drawings	3D Modelling
Client	☐	☐	☐	☐
Consultant	☐	☐	☐	☐
Contractor	☐	☐	☐	☐
Subcontractor	☐	☐	☐	☐
End-user	☐	☐	☐	☐

9. Could you please evaluate the techniques and knowledge resources according to their effectiveness to define the rule sets for TR coordination? (1 to 5 – Not Effective to Very Effective)

	1	2	3	4	5
Specifications	☐	☐	☐	☐	☐
Related Standards (BICSI, TDMM, etc)	☐	☐	☐	☐	☐
Meetings	☐	☐	☐	☐	☐
Workshops	☐	☐	☐	☐	☐
2D Drawings	☐	☐	☐	☐	☐
3D Models	☐	☐	☐	☐	☐

10. During your current project in which phase all rules related to TR coordination have been agreed upon with all parties and required revisions and improvements have been done?

- ☐ Concept Design Phase
 ☐ Shop Drawing Phase
☐ Design Drawing Phase
 ☐ Construction Phase

11. In your opinion, if there is a pre-defined rule and action set, is there any improvement in the coordination process or not?

12. Could you please mark the possibly improved and fastened project phases if there is any pre-defined rule set for TR coordination?

- ☐ Concept Design Phase
 ☐ Shop Drawing Phase
☐ Design Drawing Phase
 ☐ Construction Phase

13. Could you please mark the affected sub-phases from the change in TR coordination rule sets?

☐ Concept Design Phase

☐ Room Location

☐ Room Layout

☐ Design Drawing Phase

☐ Architectural Layouts

☐ Electrical Layouts

☐ Mechanical Layouts

☐ Str. Formwork Drawings

☐ Shop Drawing Phase

☐ Door Shop Drawings

☐ Mechanical Shop Drawings

☐ Wall Shop Drawings

☐ Electrical Shop Drawings

☐ Floor Shop Drawings

☐ ICT Shop Drawings

☐ Construction Phase

☐ Slab openings

☐ Floor boundaries

☐ Wall locations

☐ Finishing Materials

☐ Door opening dimensions

☐ Wall Openings

14. According to your experiences, do you agree that the required attention is given to ICT coordination in airport buildings or not?

15. Generally in which project phase, do you think that required importance is given to ICT coordination?

☐ Concept Design Phase

☐ Shop Drawing Phase

☐ Design Drawing Phase

☐ Construction Phase

16. According to your expertise, in which phase should every party understand the importance of ICT coordination for airports?

☐ Concept Design Phase

☐ Shop Drawing Phase

☐ Design Drawing Phase

☐ Construction Phase

