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Towards an Innovative Service Digitalization in Smart Spaces: A User-Oriented Approach

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"Ignorance more frequently begets confidence than does knowledge: it is those who know little, and not those who know much, who so positively assert that this or that problem will never be solved by science."

Dedicated to all the "Digitalization Innovation" enthusiasts out there.

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Stuttgart, October 2019

Author
Mahmoud Sharf

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Glossary

The following abbreviations are used in this manuscript:

5G	Fifth-Generation Wireless Technologies
AAL	Ambient Assisted Living
AC	Air Conditioning
ADS	Autonomous Decentralized System
AI	Artificial Intelligence
AIML	Artificial Intelligence Markup Language
AmI	Ambient Intelligence
ANOVA	ANalysis Of VAriance
ASR	Automatic Speech Recognition
BLE	Bluetooth Low Energy
BMK	Basic Medical Knowledge
BPEL	Business Process Execution Language
BPM	Business Process Management
BPMN	Business Process Modeling Notation
CA	Collaboration Attitude
CG	Clinical Guidelines
CIG	Computer-Interpretable clinical Guideline
CPS	Cyber-Physical System
DEA	Department of Emergency and Admissions
df	degrees of freedom
DM	Dialogue Manager
EAN	European Article Number
EHR	Electronic Health Records
EMR	Electronic Medical Record
ER model	Entity-Relation model
FIRST	virtual Factories: Interoperation suppoRting buSiness innovaTion
GDPR	General Data Protection Regulation
GUI	Graphical User Interface
HCI	Human-Computer Interaction
HIT	Health Information Technology
HL7	Health Level 7 protocol
HRI (in Chapter 3)	Health Research Institute
HRI (in Chapter 5)	Human–Robot Interaction
HTTP	HyperText Transfer Protocol
HVAC	Heating, Ventilation, and Air Conditioning
ICT	Information and Communication Technology
INS	Inertial Navigation System

IO	Innovative Outliers
IoT	Internet of Things
JMS	Java Message Service
JSON	JavaScript Object Notation
MEMS	Micro Electro-Mechanical Sensors
MID	Mobile Internet Device
ML	Machine Learning
MS	Mean Squares
MSCA	Marie Sklodowska-Curie Actions
MT4j	Multi-touch for Java framework
NFC	Near Field Communication
NPD	New Product Development
PAIS	Process-Aware Information System
PD	Participatory Design
PIR	Passive Infrared
POS	Point Of Sale
PSS	participative software systems
PWM	Pulse Width Modulation
R&D	Research and Development
RaaS	Robotics-as-a-Service
REST	Representational State Transfer
RFID	Radio-Frequency IDentification
RISE	Research and Innovation Staff Exchange
RSSI	Received Signal Strength Indicator
SER	Seeding, Evolutionary growth, and Reseeding
SS	sum of squares
STN	State Transition Network
SUS	System Usability Scale
TAM	Technology Acceptance Model
TESTMED	An Italian research project which stands for (in English) "methods and techniques for process management in emergency healthcare"
TTS	Text-To-Speech
UCD	User-Centered Design
UI	User Interface
UX	User eXperience

Extended Abstract

Research Context

With the recent maturity of various cutting-edge technologies, many industries have been motivated to adopt digital transformation in their business. In fact, an increasing number of companies that cling to traditional physical business channels, services, and methodologies start to face the real threat of being left behind. Not only these companies struggle to extend their market share, but also they can not retain their current clients and customers. On the other hand, the followers of the digitalization wave manage to survive and grow their business by integrating the opportunities of technology to drive success and innovation. In the retail industry, the famous example of the retail-lead Amazon, which started digital retail innovation two decades ago, can now be easily recognized. Nowadays, there are many successful digital innovations include Airbnb in lodging and housing, Uber and MyTaxi in transportation, Car2go in car sharing, and many more other examples in almost all fields.

To this end, we can define **service digitalization** as the process of reshaping traditional analog/physical form of services with a new digital design that brings added value to both industries and their clients. One of the main reasons why some industries can not cope with the recent service digitalization trend is that they do not put enough effort and management attention into this digital transformation. For example, some companies succeed partially to define concrete regular plans for digitally revolutionizing their products but they rarely do that to the related services. Imagine the modern hospitals, where available medical devices, clinical tools, and healthcare-related products available to physicians have been updated regularly, while the service experience through the various practices and health processes is still the same as it was many years ago. Undoubtedly, the desired comprehensive digital change would be difficult to be applied with a large base of legacy assets optimized for a certain way of working. Despite that, many businesses focus their intention and employ their assets to harness digital technology, redefine service offerings, and improve the customer experience. As a result, they proceed to both lower their costs and gain a competitive advantage in their market.

To support overcoming any issues and challenges that hamper a successful and comprehensive digital transformation in industries, we need to carefully consider all the factors that add to its success. Particularly, we aim to understand the evolving **service digitalization landscape** so that companies can learn to tap the potential for service innovation and seize the digitalization opportunities. To do so, we have discussed the main elements that draw jointly the promising service digitalization innovation as shown in Figure 1. These elements are divided into two main parts: the proposed principles of service innovation to be followed, and the recent evolving technological advents and trends that can be employed to drive the digitalization revolution. As for the first part, the proposed principles are: *(i) systematic service innovation process*, *(ii) simple service delivery paradigm*, and *(iii) user-driven service design.* The second part refers to the recent striking technological trends that are profoundly reshaping the future of service digitalization while being also promoted by the emergence of the fourth industrial revolution (or as referred to by the term "Industry 4.0"). These trends include but are not limited to the *Internet of Things* (IoT), *Mobile and Pervasive Computing*, *Mobile Internet*, *Fifth-Generation Wireless Technologies* (5G), *Artificial Intelligence* (AI) and *Machine Learning* (ML), *3D Printing*, *Robotics*, etc. To sum up, exploiting these technological trends while following the indicated principles will eventually lead to the targeted service innovation, and altogether draw the promising service digitalization landscape.

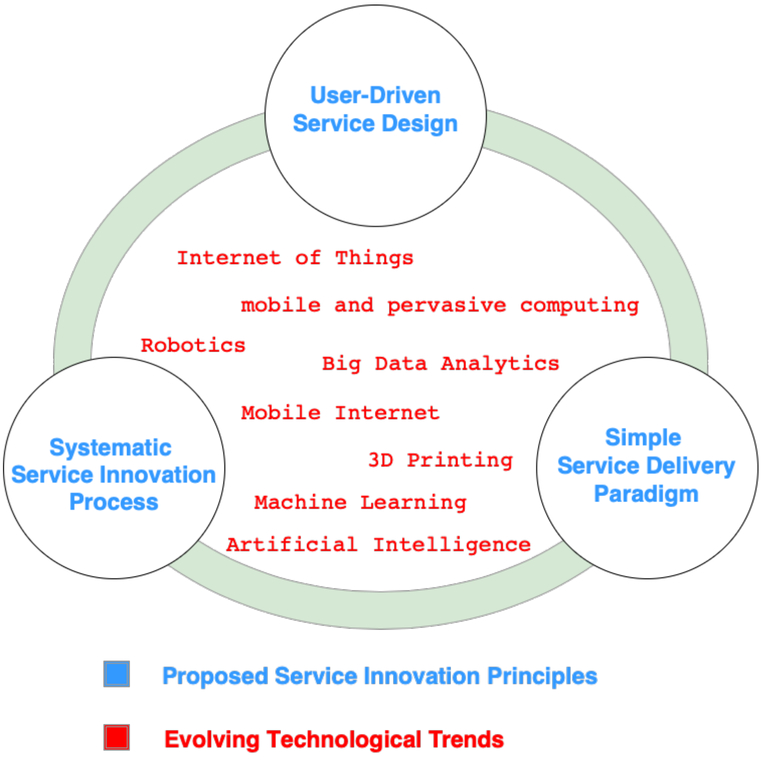


Figure 1. The landscape of a promising service digitalization innovation. The main proposed principles are marked in blue, while the recent evolving technological trends are marked in red.

One of the current game-changing technological trends that has a huge impact on the future of service digitalization is IoT, which refers to all the physical hardware devices (referred to as "things") that are employed into a specific space and connected over a network (e.g., Internet) so that they can communicate and interact (and possibly be monitored and controlled remotely). These connected devices, which are distributed through this space, collect data about their surroundings and perform corresponding actions (i.e., sensors and actuators). They can also share their collected and generated data among them in order to perform more complex actions within the whole space, through which this space can derive its smartness and can be interacted with as a unified coherent unit. In other words, connected hardware devices act actively and coherently influencing the whole environment at once, and the results of the actions influence the future computations of the devices themselves. The extension of this approach to every kind of environment is the conceptual base of *Pervasive and Ubiquitous Computing Systems*.

In order to understand the implied significance of IoT, we can imagine a world in which the environment interacts with its inhabitants. The indication here is not just providing a passive interaction, rather it involves the environment itself as an active participant. An environment that learns the inhabitants' preferences and can help each of them in a personalized way. This environment can be considered a smart or intelligent space that has always had its charm on people's imagination, as a symbol of technological progress and lifestyle of the future. This concept of **smart space** can be applied to a huge variety of environments including airports and train stations in transportation, hospitals and clinics in healthcare, schools and universities in education, museums and archaeological sites in tourism, stores and shopping malls in retail, etc. Unfortunately, the world is still far from the full implementation of this kind of scenario, but the scientific community started to put particular attention to the research fields strictly correlated to this topic. After all, IoT is a key ingredient towards a successful and comprehensive realization of smart spaces.

As we are approaching the new era of smart spaces, the digitalization of the provided services in such spaces should evolve accordingly. In fact, smart spaces try to help their inhabitants by minimizing the needed physical and cognitive effort while accomplishing tasks, and therefore, providing a more natural interaction within the space. To that extent, the main goal should be developing digital services that exploit the new opportunities of smart spaces in order to support a natural user-oriented interaction in a way that minimizes the end user's need to interact with computers as computers. In retail, for example, the self-checkout service can be redesigned innovatively in the context of a smart store. In such a store, the shopping cart can be dynamically assigned to its current user possibly by Radio-Frequency IDentification (RFID) card that securely identifies users and their preferred payment method. During the shopping process, the cart automatically identifies shopped items possibly by reading their barcodes. At the end of the shopping journey, the user can smoothly and quickly checkout from the store with only one click at the checkout *Point Of Sale* (POS) confirming all the shopping items and the final price. Such seamless interaction is the ultimate goal of exploiting smart space's digital opportunities in the generation of new innovative digital services design in order to achieve satisfying User eXperience (UX). Failing to adhere to the full potential of smart spaces during the engineering process of the digital services will probably lead to a naive service design, which in turn can result in a bad UX.

At this point, the provided **UX** is considered a key indicator of the quality of the interactive technological solution and a dominating factor for the success of any digital service. In general, UX can be referred to as the user's perception of *Human-Computer Interaction* (HCI) through a specific channel or device. In other words, it describes the user's experience of using a software system deployed into a device or across a set of devices (i.e., interaction channels or touchpoints). By analyzing this concept in the field of digital services, it can be inferred that this experience will be based not only on the 'look and feel' of the developed *User Interface* (UI) but also on its practical aspects such as usability and efficiency. This means implementing more in-depth UX values while designing the digital service instead of focusing on how to employ advanced technologies and solve UI technical challenges, which in turn considers providing more user-driven functionalities rather than usable UI alone.

In the context of smart spaces, providing innovative digital services requires a well-designed UX, which aims at investigating a comprehensive service design to derive a more natural interaction with both the physical and digital world of the space. First of all, this targeted design involves facilitating both direct and indirect users' interaction with all the connected devices/objects employed into this space, while considering their proximity to the user (physically and psychologically) at the time of interaction. Moreover, the required design should support a consistent experience across all touchpoints in the space, which does not necessarily mean to implement identical interfaces for all interaction channels through the space but rather to ensure that users motivations and goals will be supported accordingly at each interaction channel, and therefore delivering the desired coherent experience in total. Furthermore, the design should follow a user-driven methodology that pays close attention to how the actual user will be using the service in the related defined context. Considering these aspects of a satisfying UX design for digital services in smart spaces will eventually support users in a successful and joyful accomplishment of required goals/tasks in such spaces while driving the related business success.

Following this direction, many research work in HCI has been targeting how to customize applied technologies to meet humans' natural interaction in various applications and contexts. In particular, *User-Centered Design* (UCD) approaches, which promote UX by putting the actual user at the center of the system's design, implementation, and evaluation processes, have been studied. These approaches employ users' cognitive abilities (such as perception, memory, learning, problem-solving, etc.) to steer a successful realization of *Information and Communications Technology* (ICT) applications and software solutions by anticipating and eliminating all the factors that can lead to a bad UX, and therefore, a possible failure. However, despite all the recent efforts, there is still no common accepted methodology to precisely define, measure, and evaluate UX and its factors in the research literature. This is particularly true in the context of smart spaces, where each connected object, device, or interaction channel that is used by some user in this space create possibly a completely new UX, which can be seen as a momentary, primarily, and evaluative feeling for that interacting user. Given these observations, a promising UX of digital services in smart spaces should shift the attention from all the expected touchpoints (related to each digital service) in the space to the humans and their feelings while interacting with them (the "user" side of the intended digital service). To conclude, in order to capture a positive UX that leads to an innovative digital service delivery in smart spaces, we need to adopt a customized UCD approach tailored to that context and the related defined scenario, which ensures a user-driven methodology throughout the whole system's realization (i.e., design, implementation, and evaluation) process and iterative prototyping.

Research Objectives and Contributions

In this thesis, we aim to investigate and exploit the role of applying UCD methodologies when realizing (i.e., designing, implementing, and evaluating) service digitalization in smart spaces in order to leverage positive UX, so that we can derive the required service innovation and success. In particular, we have chosen three case studies to analyze and validate the effectiveness of this approach.

We have formulated our research objectives and the related contributions around the selected case studies as follows:

- **Localization as a Service**: the first case study discusses the digitalization of localization services in smart spaces. More precisely, it targets the retail industry in which a smart retail space helps users (both customers and employees) to localize themselves, the available retail items, and possibly different store's parts. As a result, an indoor navigation system can be built employing these localization services to guide users effectively while performing related tasks in this smart retail environment. While this proposed system can help customers through their shopping routine, the main purpose is dedicated to retail employees supporting them in the *pick-&-pack* order fulfillment scenario, and allowing them to easily manage items (e.g., inserting new items, updating current ones, etc.).

  Based on these details, the first objective of this thesis is to:

  O1 Define a methodology for a complete development of innovative digital localization services in a smart retail space (e.g., store or warehouse), which should support extant physical localization techniques in the space (e.g., a physical floor plan map, printed shelves numbers, etc.) while delivering a reliable and user-friendly digital indoor navigation system through the space, with a cost-effective added value. The proposed methodology must consider UX foundations while building the digital map of the retail space (knowing the store layout and where the items are located in the store dynamically), localizing persons within this map (calling for the selection of suitable technologies and technology combinations), and providing navigation and routing solution for retail employees mainly (which can be possibly extended later for customers too).

  Regarding the first objective **O1**, the following research contributions have been achieved:

  C1-1 Investigating UCD techniques to realize the proposed system while considering a real use case in the retail industry.

  C1-2 Performing a complete analysis of the requirements (both functional and non-functional) of the related retail partner.

C1-3 Building task flow diagrams based on the expected positive UX flows through all possible encountered channels in the space while following the analyzed requirements.

C1-4 Implementing a running prototype of the system that deploys the required digital localization service.

C1-5 Validating the acquired UX through a robust evaluation user study considering main quantitative and qualitative measures related to the defined retail scenario.

This research part was conducted in the context of an EU-research project called "*FIRST*": virtual Factories: Interoperation suppoRting buSiness innovaTion (EU-project number: 734599) within the programs RISE (Research and Innovation Staff Exchange) and MSCA (Marie Sklodowska-Curie Actions) and "Horizon 2020" [9]. The *FIRST* project includes different work packages in different areas related to automation and business innovation in the industry. In detail, the work was conducted in collaboration with a german retail-lead industry partner of this EU project called GK Software SE (EU-registration number: 918734628). While working on this project, a one-year secondment to this company office in Germany was arranged for better collaboration on the aforementioned topics. Besides this concrete research topic, the secondment included attending many seminars and presentations for different speakers from both academy and industry in various innovation topics regarding the retail industry.

- **Clinical Guidelines as a Service**: Healthcare is considered one of the most important fields for human development, and a revolutionary industry with a significant business segment. Recent efforts try to ensure more efficient and personalized delivery of care procedures by enabling flexible access to medical and patient-related information empowered by advanced distributed clinical mobile technologies among healthcare practitioners. To that extent, this case study targets the healthcare industry and is directed towards providing the required clinical guidelines as a digital service to doctors while delivering the needed care to patients. In a smart healthcare space, this digital service can be deployed on mobile devices, and their execution and mobile orchestration among clinical staff can be further supported by the connected medical objects and devices employed in the space.

  In order to achieve the required structured implementation of the proposed service framework, the second objective of this thesis is:

O2 Define a generic development methodology for realizing innovative digital services facilitating clinical guidelines enactment and fulfillment in a smart healthcare space (e.g., hospital or clinic). This methodology should provide a system that employs advanced technologies in such a space, with the main focus on utilizing clinical mobile technologies, to support doctors in a personalized and patient-centered delivery of healthcare operations. Besides, this methodology should promote positive UX practices of working doctors ensuring a patient-centered clinical operation in such a challenging environment by eliminating overwhelming cognitive and physical demands while allowing a non-invasive interaction with the system, which in total alleviates expected medical errors.

Regarding the second objective **O2**, the following research contributions have been achieved:

C2-1 Investigating UCD techniques to realize a digital clinical system that provides the required clinical guidelines as a digital service while addressing the chest pain clinical guideline as it is considered a common clinical case study in emergency healthcare.

C2-2 Analyzing the general nature of healthcare processes and their related clinical tasks in chronological order, from patient registration until patient discharge, in order to correctly identify and collect the related clinical characteristics of the selected clinical guideline and derive corresponding patient-specific care pathways that can be digitally implemented.

C2-3 Introducing a reasonable digital representation of the generated care pathways by utilizing the Process-Aware-Information-System (PAIS) model and exploiting concepts from Business Process Management (BPM) in order to ensure process-driven automation and execution of clinical tasks following a proper enactment of the whole clinical guideline.

C2-4 Harnessing the required positive UX by adopting a multimodal graphical user interface (GUI) with both vocal and touch interaction features coupled well with the process-driven execution of the clinical tasks. This multimodal interaction supports doctors to flexibly execute clinical guidelines, switching dynamically between the touch and hands-free (i.e., vocal) modes as required for the proper fulfillment of care procedures.

C2-5 Implementing a running prototype of the system that deploys the required digital service, and validating the acquired UX through a robust user evaluation performed in a real hospital with the actual users (i.e., doctors) by analyzing the usability and effectiveness of the system.

This research part was partially supported by the Sapienza grants TESTMED and SUPER and performed also in the context of the Centro Interdipartimentale "Information-Based Technology Innovation Center for Health" (STITCH).

- **Power Saving as a Service**: in this case study, we aim to provide digital services for power saving in smart spaces. Such services include controlling lighting, ventilation, air conditioning, heating, etc., based on an auto-detection strategy of the inhabitants' presence and their current location in such a smart space. This application tends to provide a power-saving solution with an added value in huge spaces with many changing inhabitants (i.e., too many inhabitants that dynamically enters/leaves/changes location within the space). Furthermore, it can be extended to many contexts like smart home, smart store, smart hospital, smart museum, etc. Considering UX measures of such application in smart spaces will be a dominant factor for its widespread and innovation success.

  Based on these details, the third objective of this thesis is to:

O3 Introduce a user-oriented development methodology for digitalizing automated power-saving services in smart spaces (e.g., smart home), while focusing on lighting control as the main use case that can be extended to other use cases. This methodology should skillfully employ available advanced technologies that can be integrated into such a space in order to support its inhabitants while performing ongoing activities and related tasks. Additionally, positive UX practices should be considered carefully (e.g., how fast/smooth should light be turned on/off, handling multiple users at different zones at the same time, etc.) by observing the nature of the inhabitants' navigation pattern influenced by their usual related tasks while being in the space. Such UX considerations should alleviate overwhelming cognitive and physical demands needed to simultaneously control many different power-consuming services and devices in the space, while effectively delivering the required power-saving feature.

Regarding the third objective **O3**, the following research contributions have been achieved:

C3-1 Investigating UCD techniques to realize a digital system that provides automated power-saving services for helping users to reduce and control power consumption while navigating the space based on the current location of the navigating user (i.e., using location-based services).

C3-2 Analyzing the required technologies and related technical structure for implementing such digital services, while promoting simplicity and usability.

C3-3 Implementing a running prototype of the system that deploys the required digital services while considering positive UX flows that space's inhabitants would naturally adopt.

This research part was conducted in collaboration with the "Service Computing Department" at Stuttgart University.

Other Contributions

Since the start of the Ph.D. program, the conducted research activities related to applied HCI and UCD are distributed in various topics around service digitalization and targeted innovation to enrich the research perspectives and skills, and therefore, to guide the core outcome of this program which is presented in this Ph.D. thesis. Besides this final main outcome, other research activities are conducted targeting the evolution and application of UCD approaches.

- **Evaluating Humans Collaboration Attitude towards Service Robots in Symbiotic Autonomy Settings**: given the aforementioned research objectives and the related selected case studies discussing the important role of applying service-oriented computing in localization, clinical guidelines, and power-saving while adopting UCD approaches to achieve the required service digitalization innovation, this part is directed towards the context of *Robotics-as-a-service* (RaaS) which has a significant trend in the future of digitalization and smart spaces. These RaaS units are considered part of *Autonomous decentralized systems* (ADSs), whose components are designed to operate in a loosely coupled manner and data are shared through a content-oriented protocol, which can be easily integrated with other IoT and *Cyber-Physical Systems* (CPSs) [236, 302, 274]. In particular, this research is one of the initial efforts focusing on understanding the opportunities and challenges of integrating autonomous robots in future smart spaces, where the humans need to collaborate efficiently with them in performing tasks.

  To that extent, in order to operate in human-populated environments, robots need to show reasonable behaviors and human-compatible abilities. In the so-called *Symbiotic Autonomy*, robots and humans help each other to overcome mutual limitations and complete their tasks. When the robot takes the initiative and asks the human for help, there is a change of perspective in the interaction, which has not yet been specifically addressed by HRI studies.

  Based on these details, the fourth objective of this thesis is to:

  O4 investigate the novel scenario brought about by *Symbiotic Autonomy* in HRI, by addressing the factors that may influence the interaction.

  Regarding the fourth objective **O4**, the following research contributions have been achieved:

C4-1 Introducing the term of "**Collaboration Attitude**" to evaluate how the response of users being asked by the robot for help is influenced by the context of the interaction and by what they are doing (i.e., ongoing activity).

C4-2 Performing a first user study and presenting its results which confirms the influence of conventional factors (i.e., proxemics) on the Collaboration Attitude, while it suggests that the context (i.e., relaxing vs. working) may not be much relevant.

C4-3 Performing a second user study to better assess the influence of the activity performed by the humans in our population, when (s)he is approached by the robot, as an additional and more compelling characterization of context (i.e., standing vs. sitting).

While the experimental scenario takes into account a population with distinctive characteristics (i.e., academic staff and students), the overall findings of our studies suggest that the attitude of users towards robots in the setting of *Symbiotic Autonomy* is influenced by factors already known to influence robot acceptance while it is not significantly affected by the context of the interaction and by the human ongoing activity. Such findings can help to reshape innovative future RaaS design by anticipating such UX factors and addressing them skillfully in the service design. Chapter 5 discusses this research work related to UX validation via controlled user studies in the context of *Symbiotic Autonomy*, where humans' collaboration attitude towards service robots was quantitatively and qualitatively measured and analyzed.

This research part was conducted in collaboration with the Ro.Co.Co. Laboratory of the Department of Computer, Control and Management Engineering "Antonio Ruberti" at Sapienza University of Rome.

- **Evolving User-Centered Design towards Participatory Design in Service Digitalization**: another research has been conducted discussing the promising evolution of UCD towards PD (**Participatory Design**) and the related role in delivering service digitalization innovation and success. Such evolution is directly related to the arising of new technologies ranging from smartphones to social networks which are constantly increasing interactions between people. In the ICT community, adapting technology to human nature is the key concern of UCD. However, UCD tends to neglect the emerging social dimension of technology: users are consulted in the design process, but they do not have any direct involvement or creative control over the developed technological solutions. On the other hand, the collaborative and social nature of the design process is getting increasingly explicit in the Product Design community, where PD approaches are applied to involve stakeholders, designers, and end-users in the creative process of new products.

  Based on these details, the fifth objective of this thesis is to:

O5 investigate how the integration of the unique features of PD into UCD can lead to innovation in the design process. We advocate that such innovation can be obtained by giving the right voice not only to the users who reach consensus in the design process but also to the marginals.

Regarding the fifth objective **O5**, the following research contributions have been achieved:

C5-1 Providing a deep analysis of the state of the art of Participatory Design in both ICT and Product Design communities.

C5-2 Providing an exploratory model with some experiments to create innovation in the design process.

C5-3 Introducing a Visual Analytics system to support the user interaction in the participative process.

This research is detailed in Chapter 6 that discusses how to push forward UX of digital services by evolving UCD towards PD in which actual users participate actively in the whole design and prototyping process of the software (similarly to the product design process).

This research part was conducted in collaboration with the HCI Laboratory of the Department of Computer, Control and Management Engineering "Antonio Ruberti" and the Department of Planning, Design, and Technology of Architecture at Sapienza University of Rome.

Parts of the aforementioned work have been published in the following papers:

[225] **A. Marrella, M. Mecella, M. Sharf, T. Catarci**
The TESTMED Project Experience. Process-Aware Enactment of Clinical Guidelines through Multimodal Interfaces. arXiv preprint. arXiv:1807.02022 (Computers and Society (cs. CY)), (2018)

[84] **T. Catarci, F. Leotta, A. Marrella, M. Mecella, M. Sharf**
Process-Aware Enactment of Clinical Guidelines through Multimodal Interfaces. MDPI Computers; 8(3):67. https://doi.org/10.3390/computers8030067 (2019)

[333] **A. Vanzo, F. Riccio, M. Sharf, V. Mirabella, T. Catarci, Nardi, D.**
Who is Willing to Help Robots? A User Study on Collaboration Attitude. International Journal of Social Robotics; https://doi.org/10.1007/s12369-019-00571-6 (2019)

- **T. Catarci, A. Marrella, G. Santucci, M. Sharf, et al.**
From Consensus to Innovation. Evolving Towards Crowd-based User Centered Design. Provisionally Accepted in International Journal of Human-Computer Interaction; IJHC-D-19-00239 (2020)

Thesis Outline

This thesis is structured as follows:

- In Chapter 1, background concepts regarding service digitalization, smart spaces, UCD, and UX are provided. An overview of the promising role of employing UCD approaches in smart spaces and relevant services digitalization is shown in Section 1, while underlining advantages, disadvantages, opportunities, and challenges. In this chapter, moreover, the relevant research work of realizing service digitalization is introduced in Section 2.

- Chapter 2 introduces the first case study about digitalizing localization services that are used to localize dynamically items and navigating users within a smart retail space (e.g., store or warehouse). Based on such services, an indoor navigation system is built to guide users (both customers and employees) effectively while navigating this space, with the main focus is dedicated for retail employees supporting them in the *pick-&-pack* order fulfillment scenario, and allowing them to easily manage items (e.g., inserting new items, updating current ones, etc.). A complete system realization (i.e., design, implementation, and evaluation) while adopting UCD approaches is demonstrated in this chapter.

- Chapter 3 discusses the second case study about enacting clinical guidelines as digital services in the context of smart healthcare spaces (e.g., smart hospitals). The aim is to help clinical practitioners to deliver an efficient patient-oriented operation of care procedures by leveraging advanced distributed clinical mobile technologies while adopting UCD methodologies. The chapter describes the proposed system including the implemented methodology and the conducted evaluation study.

- Chapter 4 illustrates the third and last presented case study of digitalizing automated power-saving services in smart spaces. It describes a general service framework following UCD methodologies used to implement a lighting control system as the main use case that can be extended to other use cases. This chapter describes the implemented system with two different possible architectures that can be validated with a user study.

- Chapter 5 presents the first part of the additional contributions conducted during the doctoral program in the context of HCI and UCD in service digitalization. This part discusses the research work related to investigating some UX factors of RaaS by conducting UX validation via a controlled user study in the context of *Symbiotic Autonomy*, where humans' collaboration attitude towards service robots was quantitatively and qualitatively measured and analyzed.

- Chapter 6 presents the second part of the additional contributions conducted during the doctoral program in the context of HCI and UCD in service digitalization. This part discusses how to push forward UX of digital services by evolving UCD towards PD in which actual users participate actively in the whole design and prototyping process of the software (similarly to the product design process).

- Chapter 7 concludes the thesis by discussing the collected results and main findings of the proposed UCD approaches in deriving service digitalization innovation in Section 1, while investigating the possible considerations of the future work direction in Section 2.

Chapter 1

Background

1 Service Digitalization in the Era of Smart Spaces: Opportunities and Challenges

1.1 The Concept of Digitalization

Evolving technologies have been reshaping everyday life. New possibilities have been brought to realize new ideas, opportunities have been given to tackle many persisting challenges, and many outdated processes have been renovated and facilitated by the advent of new cutting-edge technologies. Such technological revolution has been changing not only humans life, but also their mentality and way of thinking. In other words, humans nowadays are driven by technology to think about their future. This technological shift covers many fields including agriculture, industry, transportation, trading, health, education, etc.

One of the main concepts of this technological attitude is digitalization. As its name implies, this concept can be referred to as the process of converting physical/analog applications into virtual/digital form facilitated primarily by the recent emergence of electronic digital technologies. This concept mainly started with the invention of electronic digital computers which can be considered one of the most famous and important technological inventions of the last century. In order to better understand this concept, we need to distinguish between the terms digitization and digitalization. The term digitization refers to the process in which analog physically-stored information (like written content represented in books or papers, video or acoustical content recorded electrically or magnetically on tape, etc.) is converted into a virtual digital format that can be easily stored on any digital computer or related digital storage device. In the era of the current digital world, the major benefit of the digitization process is to make information digitally available, and therefore can be easily processed, edited, stored, shared, secured, and accessed. On the other hand, digitalization comes into play after digitization, which refers to the process of utilizing digitized information of a specific domain in a way that can lead to a simplified (and probably automated) digital version of the related physical/mechanical operations, services, or even products in that specific domain (or possibly in other relevant domains).

Once the digitalization concept is realized by applying digitized information to generate digitalized applications, the new opportunity of digital transformation becomes very feasible. This wider concept refers to a whole business renovation by transforming all business processes, operations, services, and applications into a unified integrated digital platform driven by related trending new technologies in that business field. In other words, this concept shifts the whole business into the digital world by integrating all related digitized data and digitalized applications, while bringing completely new business models, deriving a competitive advantage, and creating an added value through saving resources (especially time and money).

For instance, business transformation can be applied to the healthcare industry like in modern hospitals. In this context, all the information about patients (their health profiles, clinical history, assigned doctors, additional personal information,etc.), doctors (their medical qualifications and experience, list of assigned patients, related clinical department, additional personal information, etc.), and the hospital institution (other workers information, other locations if any, financial and statistical information, etc.) together with the universally-applied clinical guidelines can be digitized and inserted into a unified digital platform. Later, this digitized information can be used to build digital operations, processes, and services for the hospital like comfort patients' registration by automatically assigning new patients to available doctors (based on their already-stored digital profiles), organizing doctors and clinical staff easily (based on their scheduled working times, assigned clinical tasks, etc.), facilitating the work of doctors and other healthcare practitioners (by utilizing the digitized clinical guidelines to automatically derive the required healthcare path for each related patient), and controlling hospitals' resources (available rooms, clinical staff shortage, needed clinical tools/equipment, etc., which can help to order required maintenance services automatically when needed or call doctors from other nearby hospitals in case of emergency). This example of digitalizing the healthcare industry shows how business innovations brought by new digital transformation can revolutionize other industries as well when applied accordingly.

The digital age has only just begun to change our life aspects of how we live, work, think, and plan. As there will be new evolving technologies facilitating digital transformation, digitalization will redefine businesses further and bring more innovations. Part of these innovations is brought by service digitalization which is part of the promising digital transformation. Service digitalization focuses on redefining traditional service forms into a new digital one utilizing digitized information skillfully. Referring to the example of the digital transformation in the healthcare industry discussed in the previous paragraph, many healthcare services can be digitalized bringing added value to both the industry and prospected users. One example is discussed in detail in Chapter 3, which presents how clinical guidelines can be implemented as a digital service that supports doctors in delivering patient-centered clinical operations while minimizing overwhelming physical and cognitive demands imposed in such a challenging environment in order to alleviate expected medical errors. Such digital services provide vital examples of how digitized information (i.e., patient-related and medical information) can be utilized with evolving technologies (e.g., clinical mobile technologies) to derive the promising innovation of service digitalization.

To that extent, and in order to acquire the opportunities brought by service digitalization, we have to consider carefully the related issues and challenges. One issue is that some industries rarely dedicate any resources for adapting to the digitalization trend. In other words, they do not put enough effort and management attention into this digital transformation. For example, some companies succeed partially to define concrete regular plans for digitally revolutionizing their products but they rarely do that to the related services. Imagine the modern hospitals, where available medical devices, clinical tools, and healthcare-related products available to physicians have been updated regularly, while the provided service experience through the various practices and healthcare processes is still the same as it was many years ago. Another challenge that obstructs the desired comprehensive digital change is the nature of legacy systems employed in big industries. Such legacy systems with a large base of assets are optimized for a certain way of working, and applying digital transformation in such scenario requires a very sensitive and complicated work to carefully analyze the related traditional processes, understand the suitable technologies that can be involved, and redesign the required digital architecture accordingly.

Towards that direction, we need to investigate a common effective methodology that drives a promising service digitalization by correctly identifying all the factors that add to its success. For instance, since services nature is evolving rapidly in recent years, mastering only the traditional aspects of service delivery is no longer sufficient. In fact, the evolving service landscape should be understood perfectly so that companies can learn to tap the potential for service innovation and seize the digitalization opportunities. Practically speaking, three main principles need to be pursued to achieve an innovative service digitalization:

- **Systematic Service Innovation Process**: Services, similar to products, have a shelf life.

Certainly, customer needs and demands evolve, and therefore, expectations of the related services correspondingly change, while new opportunities are constantly brought by new technological possibilities. Consequently, the flow, architecture, and employed technologies of services should be regularly checked and refreshed, just like products are. Many companies think of Research and Development (R&D) as exclusively for product development. However, when they dedicate resources and management attention for systematic development and refinement of their service offerings, they can make significant improvements. In retail as an example, retailers can dedicate a cross-functional (R&D) unit that regularly works on overhauling the in-store customer experience and improving employee satisfaction. To do so, an end-to-end approach should be adopted considering every aspect of store operations, from customer checkout to warehouse management processes.

- **Simple Service Delivery Paradigm**: Recent promising direction points to skillfully combine new technologies with process improvements to make services straightforward and more pleasing. However, it is worth mentioning that big companies with legacy IT systems and firmly-established processes usually struggle to follow this direction for simplifying their services. This issue can be possibly addressed by rethinking current service operations the way their actual users do. In the banking industry, for example, an effort can be made to simplify the services of loan-giving process by employing combined technologies. To do so, the banking system has to form a team of project managers, loan-handling specialists, and software developers who should redesign the process from end to end, eliminating unnecessary tasks and simplifying the customer experience, while keeping the new process design compatible with the bank's legacy IT systems. The recent web and mobile banking solutions show a practical example of delivering a simplified time-saving banking service with a popular acceptance by users. Additionally, adopting these solutions lowers management costs and overhead associated with the process.

- **User-Driven Service Design**: Firms have always sought to understand customers better in order to tailor services to their needs. Practically, however, the main focus has always been on following the business-oriented policies to automate provided services and possibly cut down the related costs. There is still a lack of understanding of the actual users for whom the services will be provided. Additionally, customers' expectations nowadays regarding the provided services' usability and quality have significantly increased. Users demand greater customization, personalization, and mobility of the expected services. When they experience new service innovations in some industries, they similarly expect to experience them in others. For instance, the innovation in providing user-centered airline check-in services is expected to be similarly found not only in other transportation services (e.g., trains, buses, rented cars, shared cars and bikes, etc.) but also in other domains like retail and related shopping services. As industry boundaries increasingly blur for customers, companies must look for new ideas of how to deliver services with a satisfying UX.

In addition to the aforementioned principles, many striking technological trends profoundly reshaping the future of service digitalization, which are also promoted by the emergence of the fourth industrial revolution (or as referred to by the term "Industry 4.0"). These trends include but are not limited to IoT, *Mobile and Pervasive Computing*, *Mobile Internet*, *Fifth-Generation Wireless Technologies* (5G), *Artificial Intelligence* (AI) and *Machine Learning* (ML), *3D Printing*, *Robotics*, etc. Figure 1 shows that exploiting these technological trends while following the indicated principles will eventually lead to the targeted service innovation, and altogether draw the promising service digitalization landscape.

1.2 Smart Spaces and the Required UX

The quick growth of the information technology in recent years allows its application in many new scenarios and trends. One major growing trend is immersive interaction with IoT devices in the everyday life by making them effectively communicate and perform useful tasks in a way that minimizes the end user's need to interact with computers as computers. This kind of environment is called Pervasive System, and Ambient Intelligence systems belong to this class. An *Ambient Intelligence* (AmI) system is characterized by the presence of a digital environment that is sensitive, adaptive, and responsive to the presence of people. Such an environment that is adaptive to the context-specific data generated by its users on the runtime is also called a "smart space".

Therefore, we can define a smart space as any space empowered with an IoT system such as a retail store, museum, school, airport, hospital, town square, and alike, equipped with an ICT platform both sensitive and responsive to the behavior of its visitors while aiming to create an immersive experience. While current research on smart spaces concentrates mainly on technological aspects, an important need is still to provide users with a natural interaction with both the physical and digital world of this space to pursue easily their intentions. This can be realized by making the ICT infrastructure completely invisible to users while putting them at the "center" of the design to achieve deeper and faster insights. To that extent, this research is directed towards the context of immersive smart spaces with the assumption that putting the users at the center of the whole realization process offers unprecedented opportunities to achieve deeper and faster insights that can enhance personal experience (i.e., the experience while performing related tasks in this space) and make the achievement of goals easier and more pleasant. To this end, this research will be focused to devise a methodology and a general framework for creating an innovative, multisensory, psychologically rewarding UX in the interaction with the connected objects employed in a smart space while delivering the related provided digital services in such space.

Addressing UX in this field requires a different look taking into consideration a "dematerialized" interface to be evaluated, constituted by the entire interaction space, the connected objects embodied into it (sensors and actuators), their proximity to the user (physically and psychologically), and the opportunities to access and to interact with them. The achievement of this objective requires formalizing, capturing, measuring and evaluating UX in smart spaces, delineating a common ground for all concrete instantiations of such UX in the actual corresponding contexts. Following this direction, our research goal of enhancing UX in such a challenging environment of smart space can be addressed in different technological, context-related, and task-oriented aspects. Considering these aspects, we aim to provide users of smart spaces with an immersive UX by adapting technology into such an environment in an immersive user-centered way that facilitates their journey into this space until they complete their tasks or reach their space-related goals. Consequently, we have to consider the design of the provided digital services in this space covering every expected physical and digital "touchpoint" users would interact with during this journey to accomplish the corresponding tasks.

To better understand the research objectives of this proposal, an example of a concrete smart space is shown in Figure 2. This space is provided with sensors that capture and collect data about the environment (e.g., touch sensors, cameras that monitor the visitors while exploring the space, especially when getting close to any object or service touchpoint, other kinds of sensors, etc.) and actuators (e.g., auditory actuators, lights, displays, etc.) which are used to drive in a "smart way" the visit of the users in this space (e.g., to minimize time/effort needed to perform a task or call a service through the space). Notice that the main role is played by the users visiting the smart space; in fact, their interaction with the connected objects of this space allows the collection (through the sensors) and generation (through the actuators) of the required data that make it "smart" and "immersive" space. However, users are often required to identify, visualize and understand in real-time the huge amount of data coming from such connected objects, and this would immediately overwhelm them. Therefore, to make the visit and interaction in a smart space as a non-frustrating and pleasant experience, it is fundamental to create a satisfying and rewarding UX for the users visiting it.

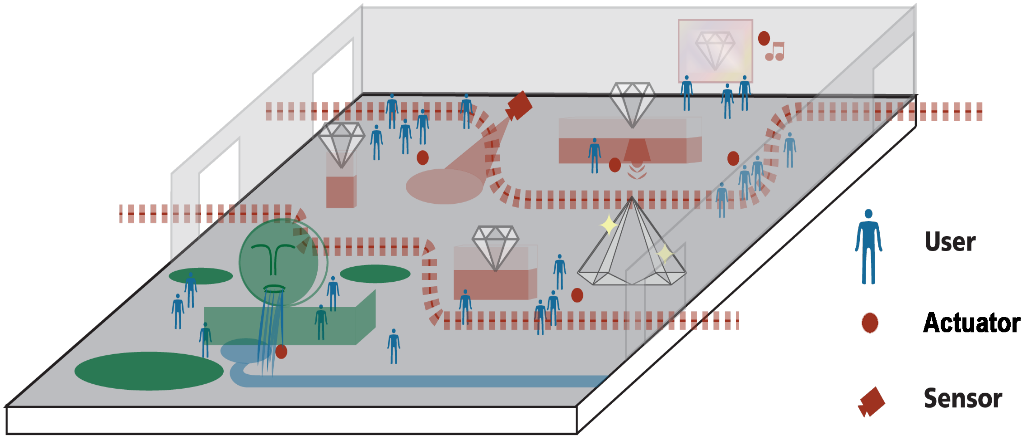


Figure 2. An example of a smart space.

From the business perspective, a user-oriented design of business-related smart spaces and their deployed digital services can have a huge impact on business success and market share. Unfortunately, there has been little research targeting this area that can help to achieve the aimed economic growth. In a smart retail store, for example, limited research recently has been focusing on the enhancement of the customer experience through the shopping journey, and on the other hand, enhancing the employees' experience while performing various retail management processes. Therefore, the current attitude should be directed towards having a user-centered digital system dedicated for the corresponding business-related smart space, which brings to its users (i.e., both employees and customers) an experience that leads them effectively and joyfully while using that space, and simultaneously, return an added value to the companies to increase their profits and market share by facilitating tasks completion for their employees and building a stronger relationship with their customers. This challenge asked for a good understanding of the different factors that form this experience design, including the business one where the attention should be paid for how to bring the advantages of the online channel (e.g., for customers to easily access and compare all related products and services, checking the availability of items according to different categories, getting offers, promotions, and discounts for next-time shopping, etc.) together with the advantages of the in-store channel (e.g., the look and feel of an item, personal care with face-to-face interaction, etc.) by coordinating these channels in what's called **Omni-Channel design**. Another factor will be related to **Service design**, which considers the segmentation of service into all the touchpoints the user interacts with chronologically in order to design and create the smoothest journey through these touchpoints of the related smart space.

To tackle the above issue, this research aims at promoting UCD development and operational paradigm for measuring and improving the UX of humans inhabiting smart spaces. Hence, the goal of our research will be focused to devise a methodology and a general user-driven and business-oriented (where the business-related context applies) framework for digitalizing services in smart spaces allowing an innovative, multisensory, psychologically rewarding UX in the interaction with the connected objects employed in this space. This needs to reconsider **UX design** (as a significant and evolving topic in HCI) and study the intersection of this field with Omni-channel design and service design to derive business success (the intersection of these domains is shown in Figure 3). The idea is to build a UX design that provides more functionalities rather than a usable UI alone and handles more in-depth values and needs of the user instead of focusing only on solving technical challenges on the UI level.

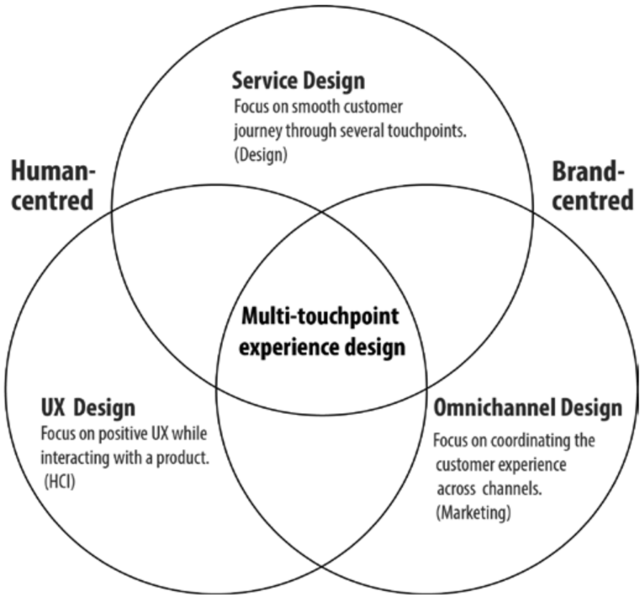


Figure 3. Multi-touchpoint experience design stems from several experience design foci.[286]

2 From Technology-Driven to User-Driven Service Digitalization in Smart Spaces: Surveying Relevant Research Work

Adapting technology to human nature is the key concern of HCI and UCD methodologies. UCD is a design philosophy that places the end-users (as opposed to the "thing") at the center and involves them in the design and development activities [77, 101, 343, 229]. It strongly involves cognitive factors (such as perception, memory, learning, problem-solving, etc.) as they come into play during people's interactions with things and/or systems. UCD is increasingly seen as essential for the creation of successful products and prototyping ICT applications, in order to prevent product failure at the end [42, 233, 313].

Under the umbrella of UCD, UX is an extended and distinct perspective on the quality of interactive technology. However, a precise accepted shared understanding of UX is still lacking in the research literature. This is particularly true in the context of smart spaces, where each product/service that is used by someone creates possibly a completely new UX, which can be seen as a momentary, primarily evaluative feeling while interacting with a product or service. By that, UX shifts attention from the actual product or called service to humans and their feelings while using them (the "user" side of product/service use).

In smart spaces, UX becomes a temporal phenomenon, present-oriented, and dynamic/changing over time. To support a positive UX, there is a crucial need to pay special attention to the involvement of the users in the process of research, development and prototype creation[55]. Additionally, recent research on assessing UX in smart spaces deals with it in a "shallow way"; this might lead to a purely subjective evaluation of the UX mainly based on the results of ad-hoc user satisfaction surveys. For example, in [44, 69, 153] the authors choose to adopt such subjective evaluation techniques to measure UX in Web-of-Things-enabled smart spaces. Therefore, one of the targets of the conducted research of this thesis is to support a "subjective evaluation" of the UX, which is acceptable mainly in static and controlled environments, with an "objectively measurable view" of UX in dynamic and changing environments like smart spaces.

To achieve a comprehensive capturing of the required UX in smart spaces, we should consider the possibilities emerging from the digitalization revolution in such spaces. These possibilities will have a major lasting impact not only on the way humans interact with the employed connected objects when performing tasks or requesting services in these smart spaces but also on the global market and involved industries. The upcoming digital transformation will drive many business models and value chains to change substantially or even vanish, while new ones may emerge at the same time. In other words, digitalization pushes towards offering digital products and services while developing innovative service-based business models. Recent examples include Amazon and Zalando in the retail industry, Spotify in the music industry, MyTaxi and Uber in the transportation industry, Airbnb in the hospitality industry, etc. As a result of its success and positive impact, many companies in various industries are now increasingly adopting digital transformation for their business, while they start to provide digital systems for their service offerings [241]. Therefore, one of the main success factors of this digitalization movement in any industry is providing related innovative service digitalization.

To follow this direction of providing innovative service digitalization, we have to consider various elements that contribute to its realization. The first and main element is to skillfully employ evolving technologies in digital services implementation. One of the early works about involving technologies in implementing services is presented in [199] about the industrialization of services. It assumes that the success of a company can be increased through the use of technologies in developing services and the resulting service innovation. According to [199], service digitalization in industries can lead to higher efficiency, lower costs, and higher customer satisfaction. Nowadays, these theoretical considerations have become reality as technology-based services are already widely used in our everyday life. Moreover, this service digitalization trend has been accelerated in recent years by the emergence of data digitization in various fields. In the research context of this thesis, smart spaces with IoT technologies contain networked and connected devices/objects that generate and share a huge amount of digitized data, which brings the great opportunity of providing related service digitalization.

Digital services offer the potential to realize significant benefits and possibly overcome some challenges of alternative traditional services. The analysis of recent market expansion summarizes how digital services contributed to the development of new markets by facilitating regular services' tasks/steps, winning new customers by meeting their expectations and offering new distribution channels. Besides, market entry barriers for digital services are relatively very few. Moreover, thanks to the flexibility provided by digital access, related digital services can be easily accessed anywhere and anytime. Additionally, digital services can save time, effort, and money, either for the industry with the needed resources to provide those services or for the end-users with the needed requirements (physically and psychologically) while requesting and using them. As for the industry, employing digital customer services is a very good example, which can significantly reduce the time, the effort needed, and operating costs by providing automated artificial agents through the various channels of telephone or the Internet. As for the end-users (e.g., customers), various examples can be seen in many scenarios like in the banking industry where financial transactions are not tied to a specific bank location, related opening hours, or queue waiting time. Further potential for digital services lies in increasing customer satisfaction, and therefore customer loyalty, by adopting individualization and customization of the provided services[293].

The advantages of employing digitalization can be easily noticed in different industries to transform traditional services into digital ones. However, other factors must be considered including a careful selection of the involved technologies depending on the nature of the industry and the type of related services to be digitalized and their characteristics. Also, we have to consider the corresponding requirements needed to support individual and customized end-user needs. Further, although the flexible anytime-anywhere digital self-services substitute the usual traditional services with regular physical/human interaction, a positive feeling of the alternative digital one should provide the psychologically important feeling of "being served" to avoid interrupting digital services as inferior, and therefore, affecting customer loyalty. Furthermore, obstacles of cultural differences among prospected users should be handled accordingly. Finally, it should be noted that the potential brought by service digitalization on a technological basis alone does not cover all aspects required to ensure a positive UX through all the expected touchpoints of the resulted digital service. An example that points out this importance is provided by [46] where an emphasize on the balance between the notions of technology and touch experience in the digital service design should be considered carefully. In this work, an assessment of the optimal mixture of human-based service and online service is conducted through a game-theoretic model. The major conclusion of this research indicates that realizing digital systems blindly with a technology-driven attitude only may have unfavorable results; instead, digital services offerings should involve the right balance of the human-based and technology-based features.

From a business perspective, business digitalization has gained increased attention recently. Many firms in a broad domain of industries have already started redesigning their business-related activities and even entire related business models to make an added value with digital resources and IT investments. Particularly, services digitalization has been presented and discussed as a promising scheme to drive revenue growth and enhance performance (e.g., [178, 179]). Therefore, numerous highly digitalized industries invest in various sections of knowledge-intensive services including finance, media, insurance, professional services, etc ([141, 139]). Besides, according to [194], research on service digitization, in general, might be categorized into two main parts: firm-focused and customer-focused research. The part of the research that is directed towards a more firm-focused viewpoint mainly discusses issues such as performance significance of digitization, service operations, service design. As an example, one of the works related to the information systems field examines how the quality of information, as the main feature for realizing digital designs, improves customer service potential and therefore leverages service performance ([298]). Customer-focused research generally investigates customers' evaluations of and impressions about digital services and the behavioral outcomes which can be concluded from such assessments. For example, many of the most significant studies on service digitalization explore how customers assess the quality attribute of the provided digital services (e.g., [252]) and how these evaluations of the various design attributes can be transformed and interrupted to an adoption behavior (e.g., [203]).

To that extent, [194] points out that top studies about service digitalization can be summarized in three major subjects. The first subject talks about measuring and assessing the quality of digital services. For instance, in [252] two scales are presented to detect how the delivered service quality in some websites fulfill the needed requirements of general online digital space. In this example, one scale assesses the end-users perception of the privacy, fulfillment, availability, and efficiency of those websites, and the other one involves assessing the reliability and effectiveness of the system. Another example in [96] detects user assessment of perceived outcomes, processes, and recovery of digital services. Moreover, in [53] different concepts regarding digital services quality based on their pleasurable aspects and experience are introduced. The second subject concerns the strategic organization of service digitalization. In this topic, some studies (e.g., [291, 70]) confirm the strategic feature of digitalization while indicating the possible opportunities and challenges of the associated digital services. In [291], it is noted that the general performance of a company can be driven by its digitalization strategy and digital services offering to meet end-user expectations (e.g., via customization) and derive an added value for the business (e.g., through dynamic pricing and customized offers). The third subject considers users' adoption of provided digital services examining the aspects that affect this attitude (e.g., [265]). In [203], for example, the adoption of digital services is discussed in terms of the *Technology Acceptance Model* (TAM), where the readiness of the employed technologies and its impact on the usage intentions is analyzed based on the perceived ease of use and usefulness. Another study is presented in [88] to indicate how emotional and cognitive experiences affect post-adoption behaviors of the users of digital services emphasizing the significant impact of their perceived usefulness on service recommendation and continuous adoption.

Surveying the scenarios in which empirical research has been investigated, we can find that existing work on service digitalization is recognized by wide variety, with many experiments inspecting elements, prior work, and outcomes of digital services in numerous different contexts. For instance, digital services quality (which represents only one single research path in service digitalization) has been studied in many different contexts including retailing, tourism, and financial services, etc. (e.g., [114, 156, 306]). Besides business practice, the topic of service digitalization has gained significant interest in the academic literature. A fundamental and fast-growing content of research work has been directed towards such terms as digital services (e.g., [342]), IT-related services (e.g., [159], or electronic e-services (e.g., [70]).

From an epistemic perspective, and according to [194], studies on service digitalization have primarily leveraged the focal points of two categories of inquiring systems ([296, 256, 113]), which are process theories (e.g., [305]), and variance theories (e.g., [178]). Process theories introduce clarifications and interpretations for phenomena of interest in terms of the sequence of events that contribute in and guide to a certain result ([191]). The prominence of process theories is in providing a complete comprehension of why, how, and in what chronology process activities unfold and get executed over time ([112]). On the other hand, variance theories present clarifications and interpretations for phenomena of interest in terms of relations between predictor (or independent) variables and criteria (or dependent) variables. Therefore, variance theories focus on the variables that are considered elements of the entity under inspection and the formularization of interpretations that encompass causal statements about relationships between these variables ([113]).

To sum up, although the complexity and multi-faceted nature of service digitalization, the different theoretical lenses have been taken, and the various contexts in which it has been studied have produced a rich body of literature that has benefited from insights of various academic disciplines (including service research, operations management, information systems, and psychology), this produced literature has a huge fragmented research landscape. Extant work on service digitization has focused on the nature and attributes of digital services (including e-services or IT-related services in some contexts as we noted earlier) and it has examined how digital services differ from traditional services (i.e., service requires personal face-to-face communication or physical interaction with various hardware tools) on key dimensions. A common notion in prior work is that digital service involves leveraging IT-enabled digital resources for value creation and appropriation in service enactments. However, little efforts have been dedicated until today to examining the whole body of work and to delineating a standard UCD approach that can be customized and tailored to any specific context and the related defined scenario, which ensures a user-driven methodology throughout the whole system's realization (i.e., design, implementation, and evaluation) process and iterative prototyping.

Chapter 2

Localization as a Service: Approaching an Effective User-Centered Digital In-Store Navigation System in Smart Retail Spaces

1 Introduction

The first case study targets a user-centered approach for the digitalization of localization services deployed in smart retail spaces to build a digital indoor navigation system. The achievement of this objective in such a challenging environment of retail space can be addressed in different technological and business aspects. From the business perspective, limited research has recently targeted the enhancement of the retail employees' experience in the pick-&-pack order fulfillment scenario including the process of navigating the retail space collecting the order items. Consequently, the attitude remains to have a system that brings to its employees an experience that leads them effectively and joyfully while navigating the retail space, and simultaneously, return an added value to the companies to increase their profits and market share by facilitating tasks completion for their employees.

Proceeding on this track, this research part aims to provide the retail workers (i.e., retail employees) with an immersive "in-store navigation" system for an indoor retail space in order to support them while fulfilling the pick-&-pack order requirements in such environment and guide them effectively through selecting/collecting the order items and possibly performing other management activities (e.g., inserting/updating new/pre-registered items). In this context, the defined smart retail space is provided with sensors that handle indoor localization services while capturing and collecting positioning data about the navigating employees, and therefore, to drive their navigation route to the selected items in a "smart way" (i.e., to minimize time needed to reach an item or provide a customized path through the space).

Since this system is mainly dedicated for retail employees (while it can be extended later for retail customers), the focus is to exploit UX characteristics for the "pick-&-pack" order fulfillment scenario in such a smart retail space. In doing so, a related real case study of a german retail-lead company (called GK Software SE) is analyzed discussing real industry requirements and proposes a cost-effective in-store navigation system that implements its localization services using only Bluetooth Low Energy (BLE) beacons. These beacons work as positioning reference point devices installed at fixed locations within the retail environment. Hence, when employees navigate the smart retail space, their assigned smart mobile devices will communicate via Bluetooth with these beacons and their location can be detected using some trilateration algorithms. Overall, the proposed system consists of three parts: (a) the BLE beacons which are embedded in the smart retail space as positioning reference points; (b) the front-end mobile application which communicates with the installed beacons to detect the changing location of the navigating employee; and (c) the back-end server that provides various services of location and map configuration while maintaining the system database. The described technical architecture exploits a standard communication framework to employ simplicity and yet to derive the targeted cost-effectiveness.

The following of this chapter is divided as follows: Section 2 discusses the main objectives, requirements (both functional and non-functional), and challenges of our research proposal based on the related real case study of a german retail-lead company in their scenario of handling pick-&-pack orders in smart retail spaces. In order to realize a user-centered implementation of such system, Section 3 starts by introducing a deep investigation of the state of the art of UX practices when applying UCD techniques and approaches in smart spaces in general and smart retail in particular to understand the challenges/limitations of the extant systems while focusing on the indoor navigation scenario, going through the technological aspects and ubiquitous computing involved, and proceeding with the relevant work of employing UX approaches and techniques to address this topic of in-store navigation in the retail field. Section 4 talks about the followed UCD methodology for realizing our proposed system describing the UX flow design for each task in the system, the digital map design and related wireframes, the proposed architecture connecting IoT devices of the retail space with the back-end and front-end processing and relevant communication, and the implementation details of the in-store navigation software prototype in accordance with each part described in the proposed architecture and design. In Section 5, an evaluation user study via a controlled experiment is conducted to validate the acquired UX of the system. Section 6 presents the collected results of the implemented system based on the conducted evaluation study. The final conclusion about the system's main findings and possible directions of future work are discussed in Chapter 7 given the abstract context of user-oriented service digitalization and innovation.

2 Research Objectives and Challenges: Investigating UX of In-Store Navigation – Gk Software Pick-&-Pack Case Study

Before checking the recent related work of adopting UX practices while implementing indoor navigation systems in different scenarios and particularly in retail, together with the correlated ubiquitous computing applied and variable technologies involved, we need first to define the research objectives to achieve and the challenges to tackle in this context. In order to do so, we want to investigate in this section the case study of the retail-lead GK Software company in their scenario of handling pick-&-pack orders with the goal of analyzing the system requirements of in-store navigation to fulfill the related tasks of this order. After doing so, we survey the related work in order to identify, evaluate, and interpret relevant scientific works concerning this specific topic and their current limitations that need to be overcome compared with our GK Software case study. In general, pre-conducted research concerning in-store navigation systems shows that different approaches use different technological means to satisfy the defined system requirements. However, the UX characteristics in this context are not fully exploited. While each approach may have several concepts that lead to a promising UX, there is no obvious solution to follow.

Hence, we will start with the formulation of the research questions that we want to address concerning this topic in Section 2.1. Then, we will go through the GK Software requirements (both functional and non-functional) to provide such UX through in-store navigation for the pick-&-pack order fulfillment scenario in Section 2.2.

2.1 Research Questions

The first step to proceed with any research investigation is the formulation of the research questions [184], which poses a particular challenge. Previously conducted research concerning in-store navigation shows that different approaches use very different technological means to build and implement the system architecture. However, the UX characteristics in this context are not fully exploited. Due to the fact that an immersive UX requires a careful design of many aspects to cover a wide variety of different UX concepts, a certain level of uncertainty remains with respect to the formulation of research questions. Each approach may have several concepts that lead to a promising UX. As there is no obvious solution to follow, ambiguities in the interpretation of each approach should be studied and analyzed in the different recent research work. Consequently, it should be noted that other researchers might come to different conclusions regarding the answers to the same research questions about this topic. Based on these considerations, we formulated the following research questions, which will be discussed as follows:

- **RQ1:** To which degree the immersiveness of smart retail spaces are founded and realized, including applicability and fulfillment of technology requirements?
- **RQ2:** What is the role of the embodied interaction techniques in providing an immersive UX in smart retail environments?
- **RQ3:** How can the main UX classes and the categories representing them be fully exploited in the smart retail environment?
- **RQ4:** What is the maturity level of user acceptance factors in smart retail environments?
- **RQ5:** What are the possibilities of enhancing UX by integrating the smart retail environment into other environments?
- **RQ6:** How to enhance the UX of smart retail environments while considering and avoiding the unpredicted impacts of such intelligent environments on humans' health, social relations and the environment.

In the following, we will elaborate on the intentions behind the research questions and provide the necessary insights.

RQ1: To which degree the immersiveness of smart retail spaces are founded and realized, including applicability and fulfillment of technology requirements?

RQ1 focuses on the analysis of how technology requirements are fulfilled and applied to derive the smartness and immersiveness of the retail space. This includes:

- embedding ICT into the environment: using very unobtrusive (or hidden) hardware, seamless web-based communications infrastructure, and dynamic and massively distributed device networks.
- advanced interaction possibilities, considering a natural-feeling human interface.
- algorithmic intelligence, considering privacy and personal data protection like General Data Protection Regulation (GDPR) compliance.

RQ2: What is the role of the embodied interaction techniques in providing an immersive UX in smart retail environments?

RQ2 investigates how the various interaction techniques are represented and embodied in the existing smart retail environments, either separately or jointly providing multi-modal interactivity, to derive a promising immersive UX. These interaction techniques include but are not limited to:

- tactile techniques (e.g., touch or skin-sensor based).
- kinesthetic techniques (limb movement based).
- vision-based techniques(e.g., eye tracking, VR, and AR).
- voice-based techniques(e.g., sound/speech detection and/or recognition).

The emergence of these interaction techniques in the design of smart retail spaces should be driven and guided by the following UX-related aspects:

- Fun, enjoyable and exciting interaction.
- Efficient, practical and intuitive interaction.
- Collaborative interaction: facilitating and catalyzing collaboration and communication between people in multi-user applications.
- Socially acceptable interaction.
- Accuracy in selecting, manipulating of, and interacting with the employed physical objects in the real world and the digital content related to them.
- Overcoming interaction challenges in specifying distance and direction in the smart space.
- Requirements for privacy and control of the interaction.

RQ3: How can the main "UX classes" and the categories representing them be fully exploited in the smart retail environment?

In general, a smart retail space with considerable immersive interaction comprises multiple instances of the main "UX classes". Each instance of these UX classes cooperates to deliver at least one or more specific aspects of this experience. In turn, the different applied instances of the UX classes must be described, coordinated and fully exploited in the design of the smart retail space. Table 2.1 summarizes the main UX classes and the more detailed experiences under each class and the related category as described in [246].

Table 2.1. Summary of the main experience classes and the experience categories representing them [246]

Experience class	Category of UX characteristic	Short description
Instrumental	Empowerment	feelings of powerfulness and achievement, being offered new possibilities by technology and expanding human perception
	Efficiency	a feeling of performing everyday activities and accomplishing practical goals with less effort and resources
	Meaningfulness	showing only the content that corresponds to the surrounding visible things in the real world, thus making it feel relevant and worthwhile in the current location
Cognitive and epistemic	Awareness	the sense of becoming aware of, realizing something about or gaining new insight into one's surroundings
	Intuitiveness	the interaction feels natural and human-like
	Control	the sense of being in control of all the possible interactions provided by the system services, and the extent to which each service is proactive and knows about the user

Table 2.1 – continued from the previous page

Experience class	**Category of UX characteristic**	**Short description**
	Trust	being able to rely on the acquired interaction content, both real and virtual (i.e., faultlessness and timeliness of the content), as well as the realism and correspondence of the digital aspect when aiming to replace a traditionally physical activity with virtual (e.g., gesture-based interaction reflected in the system in a digital way that replaces an actual physical activity)
Emotional	Amazement	the feeling of having experienced something extraordinary or novel
	Surprise	positive astonishment, 'wow-effects' and a service surpassing one's expectations in general
	Playfulness	feelings of amusement and joy in the novel way of interacting
	Liveliness	the feeling of continuous change and accumulation of the service and the physical environment, hence feeling vivid and dynamic and reviving pleasing memories
Sensory	Captivation	the feeling of being immersed and engaged in the interaction, possibly also creating feelings of presence and flow in one's activities
	Tangibility	the sense of the physicality of the digital content, and the content seeming to be an integral part of the environment
Social	Connectedness	offering novel ways for multi-modal mediated social interaction and communication
	Collectivity	the sense of collective use and creation of the content
	Privacy	1) what information about them and their activity will be saved and where? 2) how public is the interaction with the service, and how publicly the interaction-related information is delivered? 3) who can eventually access the content? 4) can people be tracked or supervised by others?
Motivational and behavioral	Inspiration	feelings of being stimulated, curious about the new immersive reality, and eager to try new things with the help of the provided interaction techniques
	Motivation	being encouraged and motivated to participate in the service community and contribute to its content
	Creativity	self-expressive and artistic feelings caused by the provided interaction techniques that trigger the imagination and serve as a fruitful interface to demonstrate artistic creativity (e.g., augmenting one's appearance using AR vision-based interactive technique)

RQ4: What is the maturity level of user acceptance factors in smart retail environments?

In the design process of the UX approaches in smart retail spaces, a key aspect to consider is to understand the user acceptance factors for such approaches. Understanding these factors is very important to derive the optimal usage of the digital system integrated into the environment and, additionally, a key indicator of its applicability's success. While the term "user acceptance" is most often intuitively understood, we need to elaborate more about it to provide a more formal and detailed measurable definition.

We first start by denoting the notion of user acceptance of technology, which is users willingness to adopt a new technical system based on their expectations of what the system would be like in use. These expectations arise from experiences and information users acquire from the world around them. User acceptance depends not only on the technical features but also on other important aspects like the social and cultural relevance of the user. The following are the main factors of user acceptance that must be carefully studied and their related maturity level in smart retail spaces should be identified and exploited in order to promote UX appropriately:

- usefulness
- value
- ease of use
- a sense of being in control: intelligence (i.e., context-adaptive, learning, and proactive behavior) of a system may be a reason for the loss of user control If the user does not understand the logic by which the system behaves, that is, the system lacks intelligibility. In such a case, the result will be a loss of user trust, satisfaction, and acceptance.
- integrating into practices
- trust
- social issues
- cultural differences
- individual differences: it is important to develop intelligent technologies for a variety of user groups, not just for those who appear to be the readiest and most willing to adopt advanced technologies, to avoid the growth of a digital divide between those who can and those who cannot use intelligent environments

RQ5: What are the possibilities of enhancing UX by integrating the smart retail environment into other environments?

With RQ5 we want to figure out how to integrate smart retail space practices and extend it into other environments, in order to reveal the ultimate UX enhancement we want to achieve. Such environments include but are not limited to:

- Living environments: e.g., home shopping, ubiquitous shopping (anywhere, anytime shopping), etc.
- service environments: e.g., social-media-based shopping (this requires implementing and handling an ecosystem of services, where new services have to compete for their share of user attention with already existing services).
- production environments: e.g., the notion of "personal fabrication" and its promising role in the future of the retail industry.

RQ6: How to enhance UX of smart retail environments while considering and avoiding the unpredicted impacts of such intelligent environments and related employed technological aspects on humans' health, social relations, and the environment?

The advances in applying state-of-art technology aspects to implement smart retail environments with immersive UX can be intuitively understood. However, With RQ6, we want to investigate the "dark side" of using this technology and better address how to anticipate, avoid and consider carefully the hidden and indirect consequences on humans' health (including shaping the physical habits and every-day practices), social relations of the smart retail environment's users, and even the environment itself.

2.2 GK Software Requirements

2.2.1 Problem Fields and the Main Use Case

The big picture that GK requirements want to draw is to achieve a workable in-store navigation solution for employees (which can be extended correspondingly later for customers) to fulfill pick-&-pack orders in smart retail spaces while providing satisfying UX. In order to realize such a concept, we have to understand the various problem fields to be addressed, including:

- Store mapping: which handles the issue of knowing how to present the store layout, and knowing where the items are stored within the store.
- Person localization: which requires to identify the appropriate (and cost-effective) technologies and technology combinations that can be used to achieve the positioning of a mobile user while navigating the store. The main technical challenges in this point might consider the accuracy issue.
- Navigation and routing: which comes after providing person localization. The main technical challenges in this point might consider the responsiveness issue.

We can think of the main use case of the system as an employee who wants to find certain items within a complex store layout. To shorten the search process, a mobile application (possibly) guides them to the respective shelf or area by providing several navigation features based on a dynamic store map. This can contain even more detailed information about items and/or retail store areas. Additionally, employees can use the system to track the flow of items and execute different merchandise management processes, like stock-taking.

2.2.2 Functional Requirements

2.2.2.1 User Story

Following this basic use case, we can think of the user story as an employee who wants to search for an item in a complex store layout. The employee started the in-store navigation application on a smart mobile device to get help about how to navigate to that selected item. In doing so, this mobile navigation application calls digital localization services to dynamically identify the changing location of the navigating employee utilizing the smart mobile's embedded technologies together with the IoT sensors/devices and technologies employed in the smart retail space. First, the application will ask the employee to log in to the system before being directed to the related homepage. Once the employee is logged into the system successfully and redirected to the related home page, the localization module of the application should start tracking the employee's navigation within the store in runtime by correspondingly identifying the current location of her assigned smart mobile. This automatic dynamic localization of the employee's device is executed using an appropriate easy-to-set-up method and cost-effective technology (like BLE beacons trilateration) that suits the nature of a big store or related warehouse. In the next step, an employee will be allowed to search for and navigate to particular items, besides, to perform other items management functionalities including inserting new items or modifying existing ones by updating/removing them. Besides, employees (regarding merchandise management) will be entitled to view their profile page and check the related information of their account and recent activity (e.g., account information, last viewed items,..etc.). Employees will be assigned their login credentials from the system administrator.

In terms of searching for a particular item, an employee first needs to select that item, either by searching its unique name (a list of suggested items that could match the string query could be provided in the search to facilitate finding that item) or can simply search for an item by scanning its barcode or typing manually its corresponding European Article Number (EAN). Afterward, and once the item is selected, the store map is loaded from the system back-end server (where it's initially stored) with the navigation path to that selected item to provide real-time navigation. Finally, and once the item is reached, the application provides additional information about that item. Regarding the items scanning functionality, the first step is scanning the item's barcode. Subsequently, the employee will be able to search/update that item if it already exists in the system, or if it's a new entry the employee can insert it into the system while assigning the location of the mobile device (in this case the scanner) as the location of that item in the store, and consequently, the item's location will automatically be sent and updated to the backend server. As a result, the existing store map will be updated.

2.2.2.2 Persona

Persona is a comprehensive image of the real user of the system, which therefore explains the typical representation of the ideal use case. It is generally based on user research and incorporates the needs, goals, and observed behavior patterns of the target user. Besides, it can play a role in many aspects, including specifying the system strategy of building the tasks, design interaction, usability design, target users practices, and usage patterns, etc. Technically speaking, Persona provides a vivid way for designers and product managers to understand the end-users and their needs pretty well. Also, it serves as an efficient communication media among team members. Nowadays, it is widely used in the software industry, UI/UX design, and more other areas. In the industry world, it is crucial before releasing a software product to figure out who will actually use and buy that product. A good user persona can help to achieve this and explain the subjective thoughts of what user needs, thus resulting in a useful (i.e., specifically with a considerable standard of usability and UX) product.

To conclude, a well-established user persona can bring many benefits throughout the whole design process, including:

- Good UX: adapting user-centric design approaches, the design and final results should meet users needs perfectly.

- Agreement for all: a good persona sets a common goal for all members involved in. In other words, it is not only an agreement within the team members (designers, software developers, team leader, product manager, etc.) of the software industry but also between the software industry and their customer who will actually use the output product.

- Improved efficiency: Persona can set a right and clear direction, making all efforts converge to the expected destination and the exact wanted result.

A proposed persona of our system targeting the employee use case is shown in Figures 4 and 65.

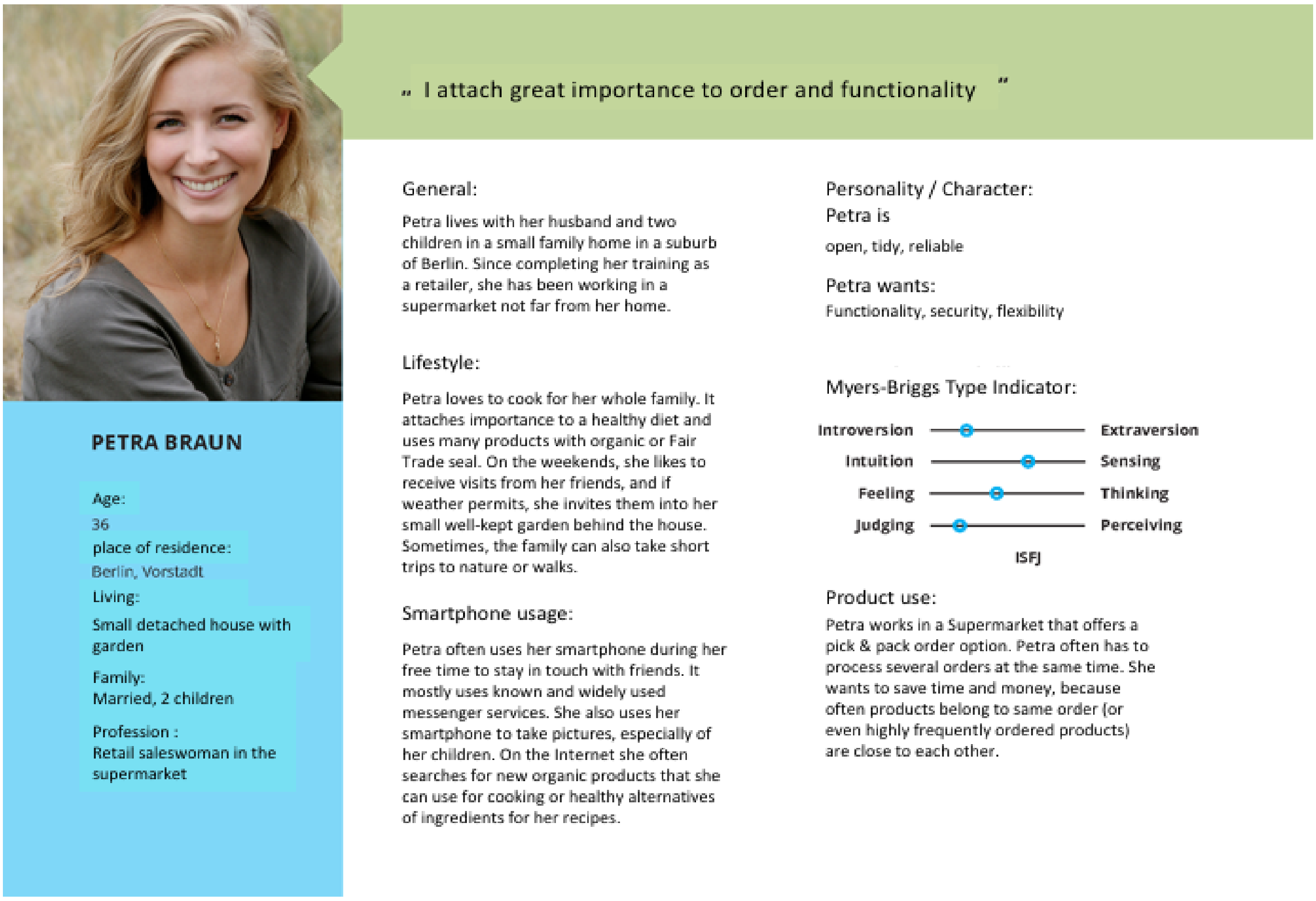


Figure 4. Persona of the actual system user - a retail employee use case.

2.2.2.3 Basic Functionality

The basic functionality needed to realize the aforementioned user story of a retail employee while using the in-store navigation application and the digital localization services can be divided into two main categories. First, there are the **main functionalities** that provide process-relevant prerequisites which enable the further execution of the application. Second, the **main tasks** that the user need to achieve. These tasks include items management tasks related to search, insert, update, and remove items(which will be reflected in creating, updating, or extending the store map), besides other user-profile management tasks.

These two categories can be summarized as follows:

Main Functionalities:

1. **Log in to the System Using the Mobile App:** The employee starts the in-store navigation application on the mobile to log in and initiate further processes. Relevant data and the UI are loaded so that the application can be used immediately.
2. **Locate Mobile Device (BLE Beacons Trilateration):** Following a cost-effective solution to provide the positioning feature, BLE beacons installed within the store (considering a sufficient coverage!) can be utilized. The smart mobile device using the trilateration algorithm can automatically and dynamically calculate the changing location of the employee's mobile while navigating the store. This information about the dynamic employee location will be later

used for setting up the location of the new/updated items by assigning the mobile's current location at the time of scanning to the scanned item.

3. **Select a Function:** The employee can have the opportunity to select between several main functions, including searching for, inserting, or updating an item.

4. **Scan Barcode/EAN of an Item:** To be able to register a new item or update a pre-registered one in the merchandise management system, the employee should be able to scan its barcode, or respectively typing its numeric EAN manually.

5. **Update Item Location Using the Mobile (Scanner) Location:** Immediately after scanning the item, the mobile sends its current location/coordinates to the back-end server. This information is assigned to the scanned item's location so that continuous tracking of all goods within the store will be enabled. Other item's information can be updated as well.

6. **Update Existing Store Map:** With the registration of the scanned item and its location in the back-end system, the existing store map is automatically updated. The respective changes are displayed immediately after the required processing is finished so that the employee can check the results of the recent performed activity.

7. **Load Store's Map from Back-End Server:** To enable the in-store navigation itself, the application needs to load the current store map after the employee defined the targeted destination (i.e., the selected item in the store). This store map is based on two components: a 2D floor plan of the store on one hand, and a 2D plan of the shelf on the other hand. Consequently, these two 2D maps can be viewed separately, and in turn, they provide a combined final 3D store map that actually will be loaded from the back-end server to the mobile device.

8. **Display Path to the Selected Item:** After the current map is loaded to the mobile, an appropriate route/path to the searched item is calculated and displayed. While navigating through the store, the mobile permanently updates its location using the calculated coordinates from the beacons trilateration algorithm until reaching the desired item location. Consequently, employees can check their current location in the store and get further information about the following navigation steps.

9. **Provide Additional Information about Items:** When the navigating employee arrives at the selected item's location, the system can show further information about that item (and possibly more information about the related section of the store). These item's information can be versatile, e.g., item number, description, price, shelf number, etc. This information can also help employees to check if they navigated correctly to the desired item.

Main Tasks:

1. **Search Item:** The employee selects an item to search for. This can be done by typing manually the item's unique name or selecting it from a list (implemented with textual search). Otherwise, this search functionality can be performed using the barcode scanning feature.

2. **Insert Item:** The employee will be able to insert a new item into the system. This can be done by typing manually the item information including a unique name and EAN. Alternatively, the employee can simply use the barcode scanning feature to insert EAN automatically).

3. **Update Item:** The employee will be able to update existing items of the system. This can be done by searching for the item first, then the employee can choose to update either only the item's location (by assigning the employee's current detected location to that item) or the item's other information (e.g., category, price).

4. **Remove Item:** The employee will be able to remove an existing item from the system. Once the item is deleted, it can be reinserted into the system.

5. **Check Profile:** Employees will be entitled to view their profile page and the related information of their account and recent activity (e.g., account information, last viewed items,..etc.).

2.2.2.4 Process Flow Diagrams

In order to present the process flow for the main use case of retail employees and the other possible use case of retail customers, the **Activity Diagram** is used. the activity diagram for the retail employee use case is shown in Figure 5, and for the retail customer use case in Figure 70.

2.2.3 Non-Functional Requirements

Usability:

The system should provide an immersive UX by adopting UCD approaches, starting with considering the human factors of the users in the initial design process until the usability testing and evaluation.

Accessibility:

The users (i.e., employees) should be able to access the different services provided by the system (e.g., search items, view store map, etc.). This requires to produce an online processing access solution (preferred), while always offering an offline instance (that can be updated periodically).

Availability:

The location detection and the real-time location tracking, enabled by the beacons trilateration algorithm, must be always available to ensure that the current position of the navigating employee within the store layout is correctly displayed at any point in time during the navigation process.

Performance/Response Time:

The transmissions between front-end and back-end (e.g., database queries, status updates, etc.) must be processed in at most a few seconds (latency preferably should be lower than 5 seconds). additionally, all components of the UI and store map have to be rendered/calculated with low latencies and sufficient frame rates, regardless of the used mobile device for navigating and/or scanning.

Backup:

The system should always keep a backup instance of its data (the backup update frequency can be customized considering new data entries).

Data Integrity:

The system should ensure that data (e.g., item location within the store) is recorded exactly as intended. This should be consistent in storing, processing, and retrieving data.

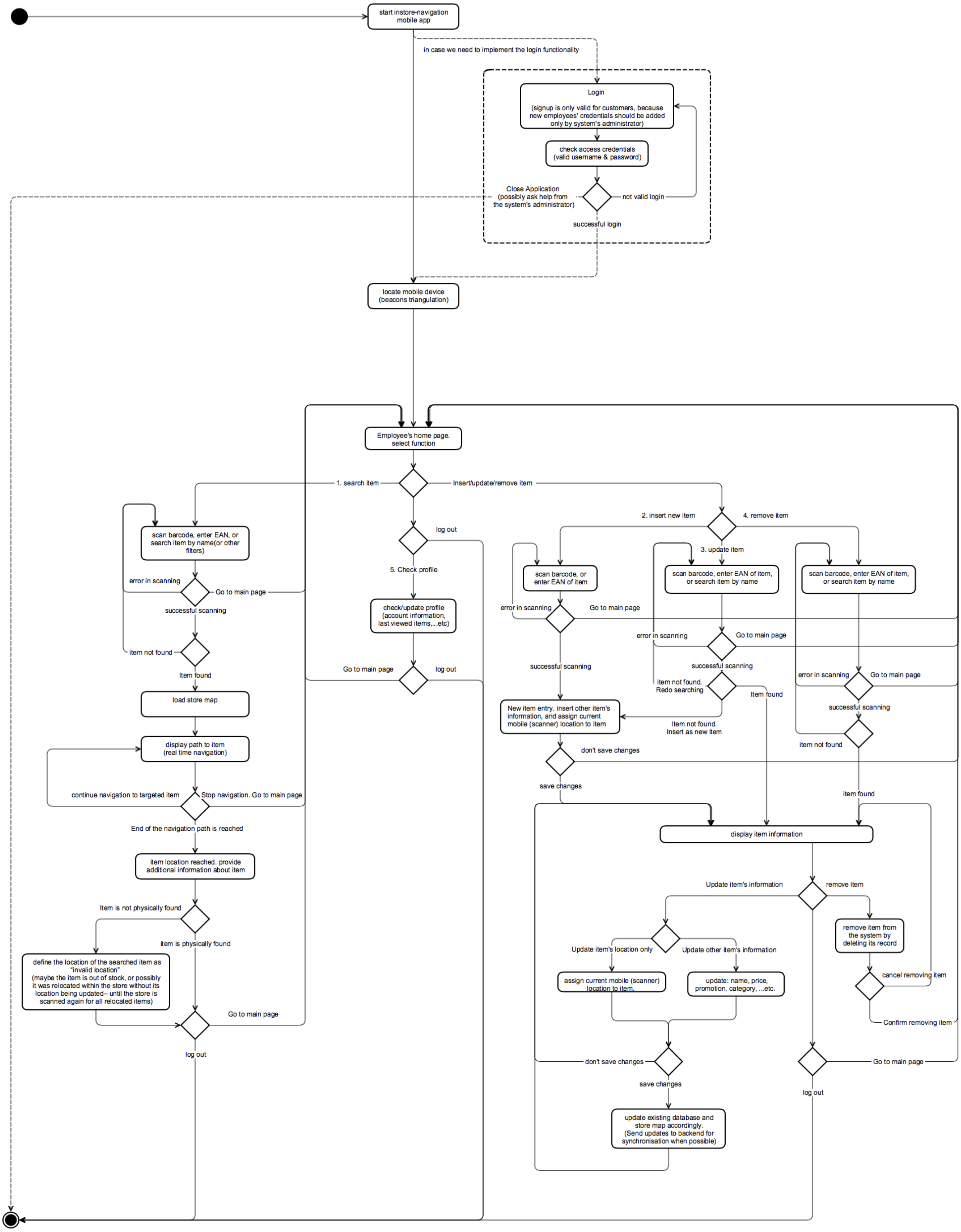


Figure 5. In-store navigation activity diagram for retail employees.

Scalability:

Multiple employees must be able to use the application at the same time. Besides, the back-end must be able to simultaneously process any amount of queries and scans within a conventional context-specific complexity. Also, The database of the back-end has to provide enough storage capacity to save the store map as well as all position references/coordinates of the items, which all should be considered carefully in the designed data model.

User-Specific Functionality:

According to the user-specific functionalities, the application upon logging into the system should detect the current type of user (e.g., administrator or normal employee). Therefore, the application should provide the corresponding functionalities according to that user type.

Quality of Service:

Providing an area-wide coverage of beacon signals is essential to guarantee a stable and fluent navigation process within the store. Moreover, maintaining an optimal flow of data by ensuring that all mobile devices will be online when necessary while using the application. Besides, The scanning module should provide detection rates with high reliability and availability. Also, the calculation of the displayed path to the desired item must be efficient for employees to follow.

Monitoring:

The employees should be able to monitor all activities regarding the continuous update and replenishment of the store map, and system administrators should be able to track any kind of user activities to maintain and optimize the system.

Installation:

Regarding the location detection property, the BLE beacons should be installed to ensure optimal coverage of the whole store map by considering the average operational coverage of every single installed beacon. Since the system uses a trilateration algorithm to locate the mobile devices, at least three beacons have to be in each part of the coverage area at any point in time. Further, stable network connectivity (either fixed like Wi-Fi access points, or mobile like mobile Internet networks) should be installed into the store to support the system's online operation mode when needed that requires a synchronized transmission of general information about new or pre-registered scanned items. Besides, all items that should be tracked and considered part of the store's map have to be equipped with barcodes and/or EAN.

Update:

During the navigation process, the items list that allows the employee to search a particular item has to be up-to-date at any point in time. Similarly, Updates of the store map that occur while displaying the navigation path to a selected item should automatically be considered for the next navigation request (or if possible even in real-time while navigating).

Migration:

The front-end mobile application must be prepared for the usage on multiple platforms with the same extent of the functionality on any device that is applicable within the system concept. Furthermore, the captured data by the front-end mobile application (e.g., while scanning, inserting, or updating an item) should be available and accessible for other business-related processes, e.g. merchandise management. On the other hand, the system should allow seamless integration of already existing merchandise management systems with respective interfaces and respective possibilities of interaction.

Security:

All captured data (i.e., item-, retailer-, and employee-related data) has to be handled according to the privacy policy. Retailer-related content and employee-related data must be encrypted and secured from unauthorized access.

Configuration:

The initial configuration of the front-end mobile application should be executed automatically without any unnecessary intervention by the employee. Also, System administrators should have the opportunity to adjust the basic settings of the system without negatively impacting the running employee processes.

Reliability:

The front-end mobile application should nevertheless provide its basic functionality, for both online processing (even in case of bad connectivity) or offline processing. The application must also be optimized to efficiently handle the limited memory and storage specifications of the mobile devices, considering both cases of online and offline processing. This calls to consider correctly which and how services are implemented on the front-end and back-end sides.

Robustness and Fault Tolerance:

The application must be secured against false or invalid inputs (e.g., when scanning an item barcode). Besides, the system should automatically avoid data inconsistencies, for instance in succession of multiple and redundant scans when inserting a single item. It should also provide an alternative solution in case of failure or service crash (e.g., the option to insert item's EAN manually if accidentally the barcode scanning module doesn't function), and must be able to recover quickly.

3 Related Work

This research part investigates how to help retail users (mainly employees, and possibly customers) to achieve a better dynamic present-oriented experience in smart retail spaces by projecting the concept of enhancing UX while using digital services in smart spaces into the business context of retail. One of the many factors adding to such experience is providing those users with a human-centered, task-oriented, smooth, and effective indoor navigation that starts from the very beginning of their journey through the retail environment until reaching the desired value (i.e., fulfilling some retail-related tasks). Besides retail, this concept of enhancing UX of indoor navigation is discussed for different scenarios and attitudes. One of these scenarios was dedicated to blind people as in [271] that proposed an indoor navigation system supported with a vocal communication interface providing better navigation through space and helping them to accomplish tasks. Another scenario was directed towards autonomous indoor navigation through mobile robots either with micro aerial vehicle [301], wheeled Mobile Robot with visual navigation [61], or variable-resolution cognitive maps [40]. Given such examples, we can conclude that in order to realize how to leverage UX correspondingly in the smart retail context, we need to employ suitable evolving technologies while considering UCD techniques and understanding the possible business potential.

3.1 Applied Technologies in Indoor Navigation Systems

Realizing a promising UX of indoor navigation (and the related localization digital services) in smart retail spaces requires adapting variable technologies into space in order to realize immersive interactivity. Such technologies include RFID tags that can be attached to persons or to moveable objects so that the objects can be tracked by using fixed readers (special-purpose radio receivers) at different locations through the space to guide the indoor navigation process of the user [147]. RFID technology can be combined with inertial Micro Electro-Mechanical Sensors (MEMS) as proposed by [275] to enable existing indoor navigation solutions for emergency situations. In [250], a similar framework suggests using Near Field Communication (NFC) technology in order to enable an easy data transfer for indoor navigation systems just by touching tags spread over a building or a complex. In a different work, the pseudolite-based indoor navigation system is discussed [180] where pseudolite works as a signal generator that transmits GPS-like signals to nearby users to provide GPS-like navigation in an indoor environment. In [311], the uniqueness of magnetic field variations is utilized to develop a methodology to aid an Inertial Navigation System (INS) in an indoor environment. The technology of INS is presented in many other projects to support indoor navigation experience either with magnetic sensors support [59], RFID tags [287], or a combination of inertial sensors, indoor Map, WLAN signals, and light sensors [198, 345]. Further, an indoor navigation system is presented in [142] based on wearable passive sensors for measuring environmental physical conditions at both known and unknown locations in the indoor environment. On the other hand, there are many techniques involved to build robust indoor navigation systems. One technique invloves using graph-based spatial model using geometric data to provide better visibility and route description for indoor navigation [54, 310]. Another technique deals with collected training data from wearable sensors during indoor navigation [143] to be applied for machine learning model dedicated to enhancing context-awareness by inferring aspects of the user's state.

3.2 Ubiquitous Computing and Indoor Navigation Systems

With the recent maturity of ubiquitous computing and the vast advances in smart mobile devices and related wireless communication, indoor location-based services have gained increasing interests as an important application of indoor ubiquitous computing [157]. Therefore, many researchers have targeted mobile indoor navigation systems because the current ubiquity of smart mobile devices together with their built-in technologies (e.g., accelerometers, magnetometers, barcode reader, compass, camera, Internet connectivity, etc.) provide information/services relevant to the current location and context of a mobile user [297, 266]. One of the main technologies, which is embedded in all smart mobile devices, is the Wi-Fi that allowed a Wi-Fi-based indoor navigation system to be built [151]. Other technologies like magnetometer of the mobile phones are utilized to build a magnetic map for Indoor Navigation [145]. Additionally, a low-cost indoor navigation system is designed using a mobile phone camera to determine in realtime the user location with the help of barcode tags [238]. Moreover, another framework leverages the camera phone module to provide a vision-based location positioning system using the augmented reality technique for indoor navigation [183]. Similarly, the idea of using augmented reality is presented by another work [237] to implement an alternative design for augmented reality interface to support indoor navigation based on localization accuracy and the users' activities, such as walking or standing still. Other works propose hybrid indoor navigation system consisting of stationary information booths and a mobile communication infrastructure feeding portable mobile devices [74], or differently using an autonomous mobile phone to establish a navigation system for indoor emergency evacuation service [167]. Another research is conducted about location-based mobile services while taking into consideration important aspects, such as the semantics of space and user models, capabilities, and context [324].

3.3 Indoor Navigation Systems in Retail

Bringing the topic of indoor navigation to our research focus of smart retail, we can detect many recent works aiming to tackle the emerging challenge of enhancing UX for this purpose by offering mobile applications that go well beyond the basic navigation, and better help users in all their activities (e.g.,[51]). Other works follow the same direction of encompassing intelligent personalized shopping assistants and "talking products" as well as intelligent shopping carts, which plan and show the way through the store according to a shopping list [188]. Such intelligent assistants compare products, point out special offers in a personalized way and give additional information about the production processes of goods. Further, the topic of retail inventory management is discussed in [81], where such a system is based on robot indoor navigation with pervasive RFID. Another system is dedicated to a self-deployable vision-guided indoor navigation system that enables users to easily deploy their indoor navigation services [200]. Additionally, a different system is proposed for indoor navigation assistance in retail environments by leveraging the structured movement patterns of shoppers, and without the need for active tagging or existing maps [267]. Towards the idea of implementing map-based indoor navigation system using smart mobile phones, another project is presented utilizing only the accelerometer and the compass, which both are readily available in modern smartphones, to accurately localize users on their indoor route, and provide them with turn-by-turn instructions through the whole way to their destination [206].

From the business point of view, there are many research work investigating how to improve customer's shopping experience technologically during indoor navigation in a way that complies with the marketing plan of the industry, and satisfying customers by providing an immersive UX during their shopping journey in the retail store. An example is a framework with two models: one for customers, and the other one for retailers (i.e., retail employees), where technology aspects of IoT and Big Data Analytics at the retail stores are utilized to target and gain more customers, and at the same time employs data mining and predictive analytics to promote marketing activities of the enterprise such as product branding, promotion, and advertising [173]. Another research discusses the opportunities and challenges for local retailing in an environment dominated by Mobile Internet Devices (MIDs) by which users (customers of a retail store particularly) gain anywhere access to the web and how this changed the retail environment [149]. This research points out the importance of bringing all the different channels like in-store, mobile, social networks, and various touchpoints during the shopping process to provide customers with a flexible and seamless experience which can be defined as "Omni-channel retailing" experience. In this context of using IoT and ubiquitous computing to empower designers for realizing an innovative UX in smart spaces, one research targets the challenges and opportunities of BLE-centred mobile systems into a museum environment [244]. With this emerging advance of IoT and ubiquitous computing, some research is directed towards a deeper understanding of UX in such revolutionary systems, and studying better the factors of user acceptance to such models that drive the success of these systems in the world of business [326, 309].

4 Methodology

After identifying the main objectives and challenges in our research topic concerning the requirements of the GK software pick-&-pack case study, and after surveying and analyzing the recent related work in the state of the art, we will proceed to present our methodology to deliver the mentioned objectives and tackle the corresponding challenges. In this sense, and complying with the GK requirements (both functional and non-functional) and their business-related demands, we employ the UCD approaches throughout the whole implementation process of the proposed prototype while trying to overcome some UX challenges and limitations in order to enhance the UX characteristics of the system.

We will start by defining the architecture of the suggested system in Section 4.1. Then, in Section 4.2 we will present a possible design of the system including a possible map representation design. Finally, Section 4.3 will discuss the implementation of all the system parts as designed for a workable running prototype.

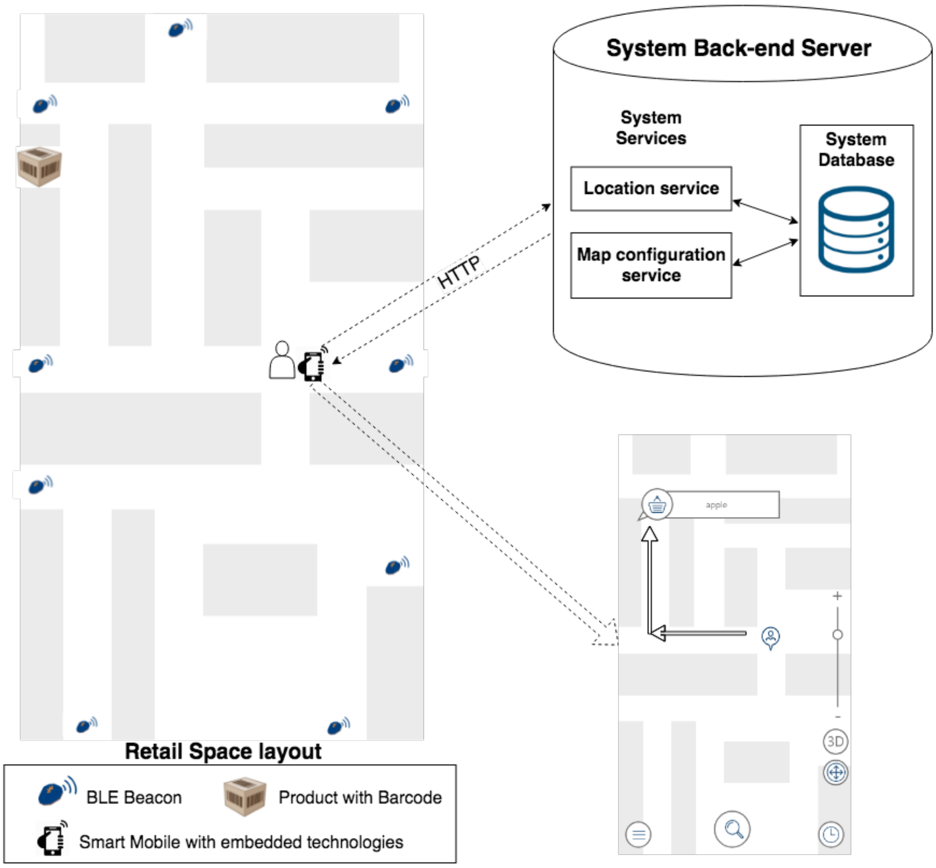


Figure 6. In-store navigation system architecture.

4.1 Architecture

The proposed system architecture is shown in Figure 6 and consists of three main parts:

- The **back-end server**, where all the main computations happen and the system's main services are provided. These services include **location service** and **map configuration service**. The server also has a **database** that stores the map data that are updated by the map configuration service. Besides, it contains all the item-related data including items' locations in the retail space, which will be mainly used by the location service to identify the locations of all the available items in the retail space map and their relevance to the current location of the navigating employee in realtime as well.

- The **front-end mobile application**, which communicates with the back-end server via HyperText Transfer Protocol (HTTP) in order to call a service. Then, the results of computation will be sent back and appropriately shown to the navigating employees on their assigned smart mobile screen. Both front-end and back-end services should be implemented carefully considering the data flow requirements, and the possible front-end mobile device specifications and technical limitations. This will ensure the smooth functioning of the front-end mobile application throughout both online and offline operation modes.

- The **IoT system**, which consists of all the smart connected objects embedded in the retail space. Mainly, the BLE beacons form the core component which will be responsible (together with the technologies embedded in the employee's assigned front-end smart mobile device) of providing a dynamic location detection within the retail space map, and this changing location will be synchronized and updated to the back-end server (possibly for a live tracking of employees' current location).

When a navigating employee starts the front-end mobile application on the assigned smart mobile device, her current initial location within the retail space will be physically detected by the available embedded IoT system in this space, mainly through the BLE beacons trilateration, and then this initial location of the employee will be communicated to the back-end server. Therefore, the first HTTP call to the server is made and the location service is requested, which will return out of the server's database the employee's exact corresponding location on that retail space's actual map, and then it will be displayed accordingly on the front-end mobile application. Afterward, when the employee wants to search the location of a specific item either by item's name or EAN, an HTTP call to the server is made and the location service is requested again to search the server's database for a query match. When this matching item is found, all the item-related information including its exact location in the retail space map will be retrieved and sent back to the front-end mobile application. Subsequently, a possible path from the employees' current location to that retrieved item location can be displayed on the application accordingly. The dynamic changes of the employee's location while navigating to the searched item will be detected again by the trilateration algorithm of the BLE beacons. Therefore, in order to ensure a coherent location update and a good refresh rate of the employee's movement, the trilateration-based localization algorithm should be triggered on a frequent basis (e.g., every one second). Similarly, these continuous location changes of the navigating employee should be tracked and communicated frequently to the server via HTTP calls to have a consistent state on both front-end and back-end sides.

On the other hand, system administrators need to create the basic map data and keep them updated into the back-end server. These map data include all buildings, floors, shelves, beacons, and their corresponding coordinates. In total, all of this information can be retrieved and gathered to form the complete store map layout of a particular retailer. In order to achieve this, the map configuration service will use these data and send it back to the front-end application to provide employees with all the needed information about the retail space map that will be visually rendered while navigating in realtime.

4.2 System Design

This section is divided into three main parts. The first part will start by analyzing the retail space map design in Section 4.2.1. The second part will elaborate on the design of the system main tasks in Section 4.2.2. The third part will present the proposed system data model in Section 4.2.3. The last part will discuss the final possible design of the system introducing the proposed wireframes of the system prototype in Section 4.2.4.

4.2.1 Map Design

Map View

The map view is the part of the front-end mobile application that presents the actual map of the retail space to the employees correspondingly on their assigned mobile devices. This requires transforming the map data and location data, which are both received through the map configuration service and location service, as raw data from the defined data model (discussed later in Section 4.2.3) stored in our system server, using a selected map drawing framework as shown in Figure 7.

During the employee navigation and while the application is running and showing the map view, the logic behind the map should run constantly displaying any location updates (i.e., updating the displayed position of the navigating employee on the existing map). These location updates will be reflected by the localization module which uses BLE beacons trilateration that works by constantly requesting the reference location of the near-by beacons (at least three) to resolve the employee's current position. Meanwhile, the system calls the location service and map configuration service on the back-end server periodically (e.g. one HTTP call per second) to fetch the data about beacons reference locations and any other updates about the retail map itself (e.g., new shelves added by system administrator, new items added by other employees, etc.). On these changes, the system should refresh the displayed map accordingly. Otherwise, if the employee is running the application in the offline mode (i.e., no network communication to receive last-minute map data updates from the server), the system will use the front-end stored data from the last online communication with the server. Finally, the map view itself should not feature any type of intelligence regarding the positioning itself since it is only acting as a middleware between the system's map data stored in the server and the front-end application as shown in Figure 8.

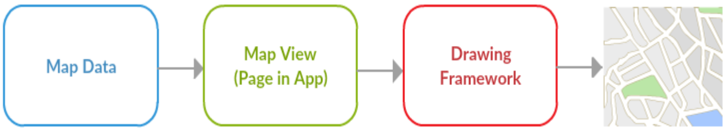


Figure 7. Steps of translating map data into map view.

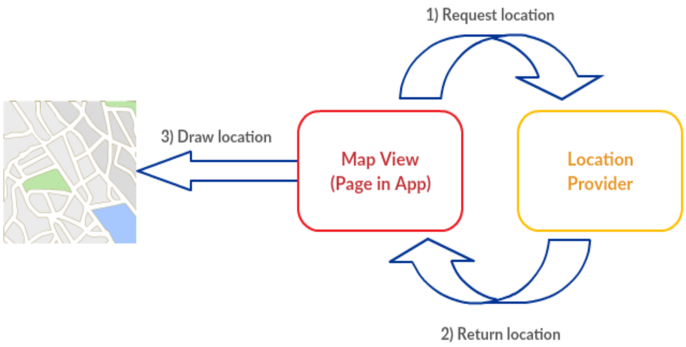


Figure 8. Process of requesting map data to render the map view.

Map Framework - Technical Evaluation

The main feature of the application will be a map that can represent the floor plan and the navigating employee location within that plan. Therefore, a framework that can create a map for the floor plan based on our input (i.e., map configuration data which is created by the retail system administrator and stored in the back-end server) is required. This framework should provide a coordinate system so that installed beacons positions can be easily mapped inside that plan accordingly with fixed X and Y coordinates to make the trilateration as simple as possible. In Table .1, we will go through a brief evaluation summary of the available technological frameworks that can be used for the store map representation.

Map and Navigation Path

A basic map could look like the one in Figure 9. The overall shape of the retail space map is originally defined by the mapping process of the map configuration data created by the retailer. The beacons are set up on various positions within this space for a continuous location detection process of the employees while they navigate within the retail map. Shelves and other elements of the map are added to the map layer. Now, a solution is required for enabling pathfinding throughout the map while considering the layout and obstacles.

One concept that can be applied to tackle this issue is **graph theory**. In this concept, every intersection between any two possible unique physical paths in the store can be mapped as a node,

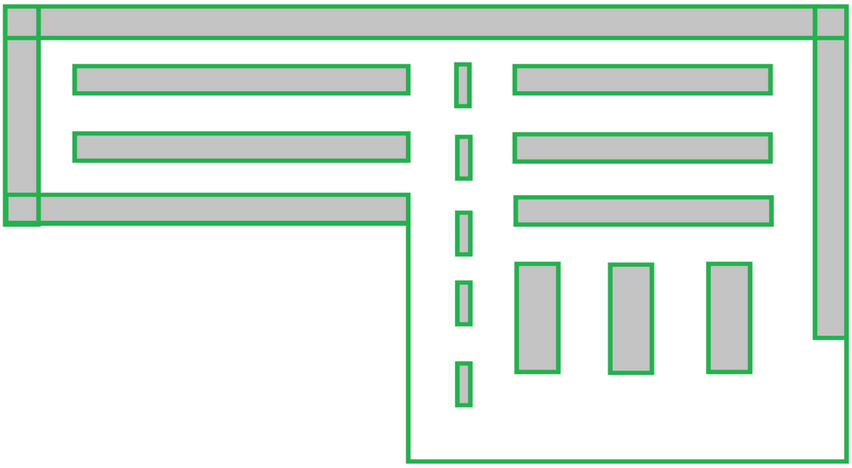


Figure 9. Basic retail space map.

and each of the actual paths can be given a weight value so that in total we can have the store mapped as a weighted graph as shown in Figure 10.

The graph theory concept allows us to wipe out some problems that other navigation algorithms might cause. However, applying this concept to the map modeling should be done carefully considering many aspects, including:

- Assigning weights to the graph paths:
  The weights which are assigned to the graph paths can have different meanings. The simplest and most efficient weighing technique would be to weigh the paths based on the distance they actually occupy between every two subsequent nodes. This allows us to use an algorithm (e.g., Dijkstra) to find the shortest way between the starting points of navigating employees and their destination as shown in Figure 11. This weighing technique could provide a good solution for the pick-&-pack use case in the retail warehouse where the items could be reached using the possible proposed short path. However, considering the case of customer navigation, this technique might not possibly be favorable in some scenarios. The first scenario is when we need to impact the navigation flow of the customer in the retail store. When using the suggested total lower-weight path instead of the customer's naive one, the customer might get navigated to a shorter route but he might not follow the route that the retailer prefers. In other words, the shorter path might not allow the retailer to apply more advanced business-related features to the navigation process (e.g., providing marketing offers based on the customer's shopping history). The other scenario can happen in larger stores, where central ways in the middle of the store are often crowded with people and carts. In this sense, the path provided could be short in distance but not actually short in time. To overcome such an issue, the weights on certain graph paths can be adjusted dynamically in realtime based on the current number of other navigating customers in that area of possible congestion.

- Assigning employees locations to nodes:
  The accuracy of the employee location detection process within the retail map, which is mainly reflected by the accuracy of the beacons trilateration, can have a considerable error rate at some points. Some technical issues could prevent such an accurate detection of the employee's exact location (which is very resource-intensive and sometimes could not be even possible). For example, one of the main issues is the non-intersecting BLE coverage circles calculated for beacons trilateration, which are the circles defined by the trilateration-based calculated distances (i.e., radiuses) to each corresponding beacon in the trilateration process. This issue is one of the most critical drawbacks of the trilateration technique, which in the worst case

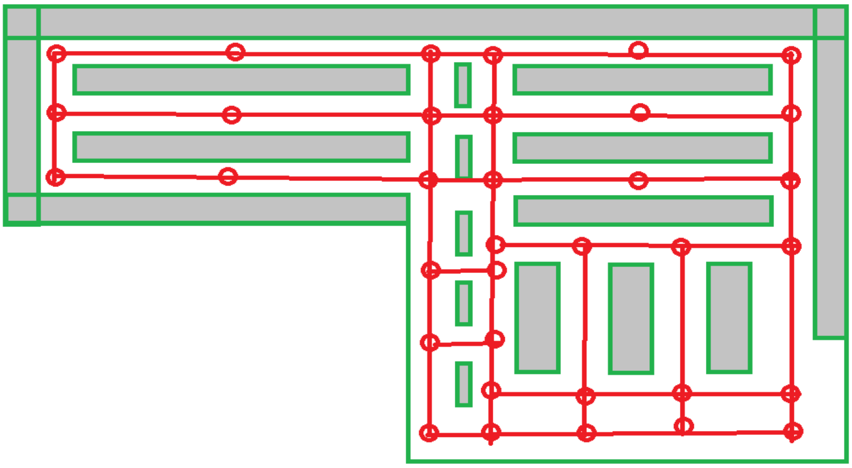


Figure 10. Retail space map modeled using the graph theory.

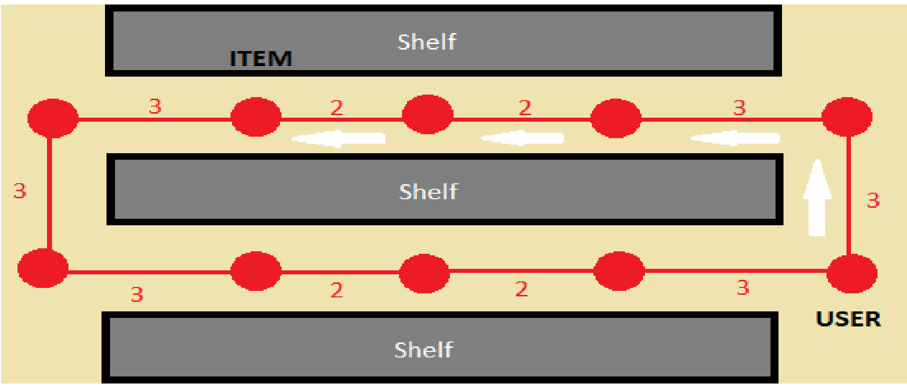


Figure 11. Possible path following the shorter weighted path.

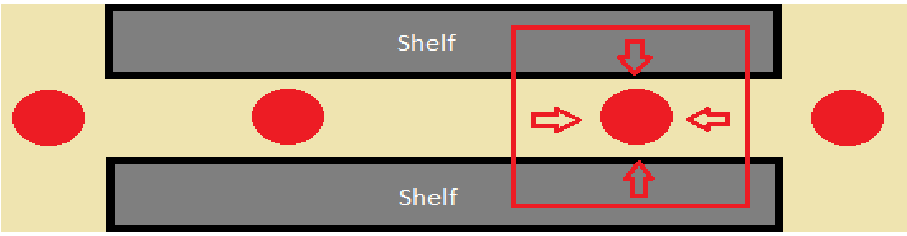


Figure 12. Enhanced accuracy of location detection display leveraging the approximation concept. The idea of mapping multiple possible employee locations along the navigation path to a single node.

(especially if not considered well at the time of beacons installation in the retail space while paying attention to other factors like space map shape and coverage, signals reflections, and signals propagation errors, etc.) can result in no trilateration circles intersecting with each other (e.g., in Figure 18a). This makes it impossible to use standard mathematical formulas to calculate the intersection area of the circles.

One option to tackle this issue is discussed in Section 4.3.1 by manually increasing the calculated trilateration distance of the circle/s which are not intersecting in the trilateration process. One way of applying this solution is by increasing the beacon's calculated distance (i.e., circle's radius) in a step-by-step manner (e.g. 50cm radius increase per step) until an intersection point with the other beacon's trilateration circles is found (as shown in Figure

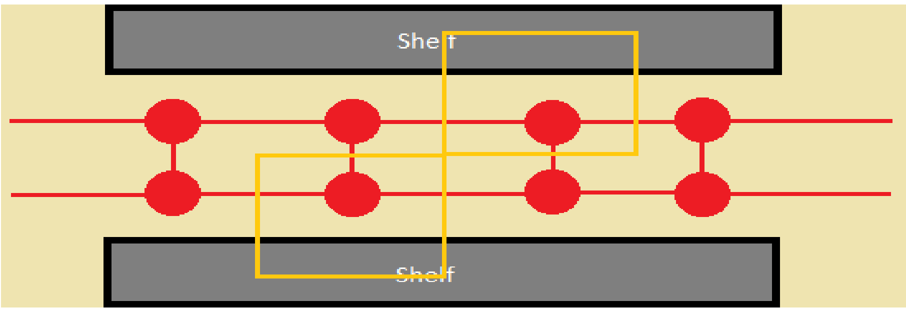


Figure 13. Large multi-meter wide corridors mapping. These corridors can be mapped as multiple rows and columns while assigning nodes to each of their intersections.

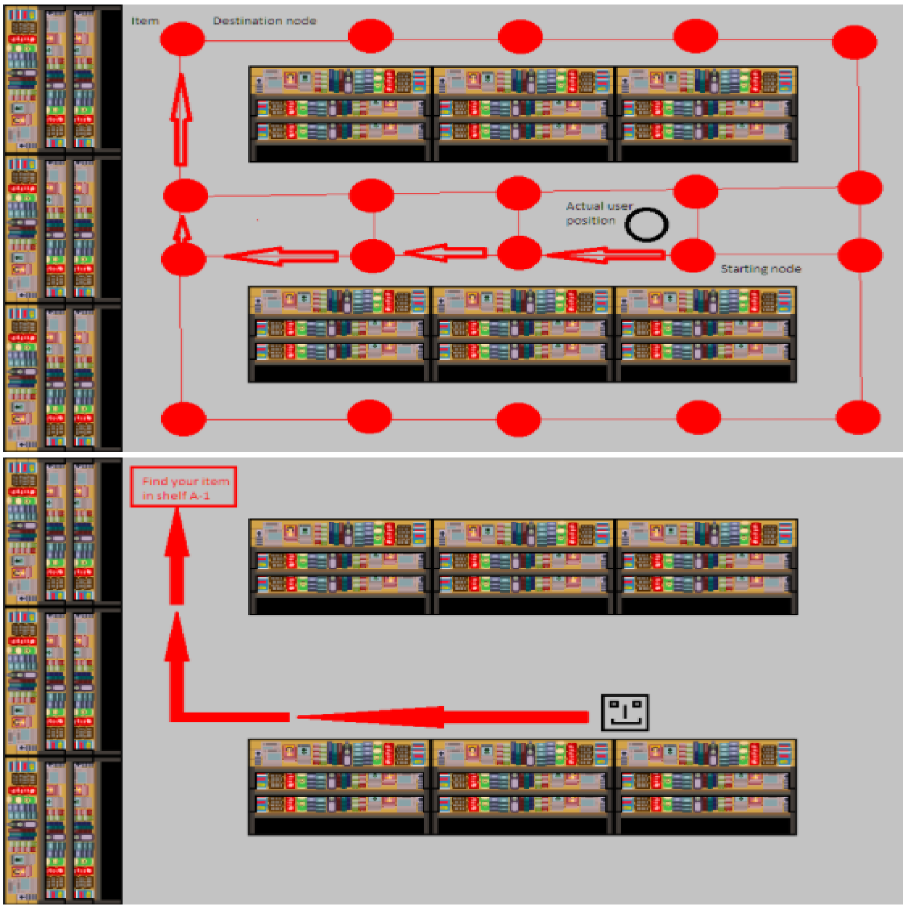


Figure 14. Displaying the navigation route in UI. Arrows can be used to guide employees through their route path.

18b). This ensures that easier and faster mathematics can be applied and might also improve the overall calculated location detection accuracy.

Another example of the expected technical issues of the beacons trilateration process is the inaccurate signal readings from the BLE beacons. As described in Section 4.3.1, these BLE signal readings from beacons will be interrupted as distances to the corresponding beacons following a specific mathematical formula. As a result, the location detection process might produce highly fluctuating location values due to the error-prone nature of the Bluetooth signals. An **approximation** of the employee location might be the best concept to apply in order to tackle this technical challenge of trilateration, as it is also easily applied to the node/graph concept. The current location of the navigating employee can vary in a certain radius around the correct spot. A high level of accuracy is also not needed for the mentioned navigation use case, as employees will not be interested in knowing their very exact locations on the map (e.g., exact location in the corridor between two specific shelves) but rather in the general meaningful definition of the location (e.g., back, middle, or front side in the corridor between two specific shelves). To let this play to our advantage, we could map a square of locations to the same certain node on our map. Therefore, we can use the averaging method by calculating the various exact locations detected during a specific time slot (e.g., 5 seconds) and then finding the average of these values, i.e., the centric one to all detected locations. Afterward, this centric detected location will be considered as the current detected location during the whole defined period, and will be mapped to the corresponding node and displayed accordingly on the map. In this way, the displayed location will have a good approximate estimation and a more stable display on the map (by avoiding frequent fluctuating inaccurate changes). On the other hand, this node approximation/mapping also requires to place other multiple nodes along the wider map paths in positions that are not intersections between these paths (as shown in Figure 12), which in turn can lead to a much easier navigation tracking process and location detection display.

- Defining the exact route in large multi-meter wide corridors:
  Large retail spaces often have corridors, for example, in the center of the store, that is multiple meters wide. Navigation through such corridors can be a little difficult because in this case the corridor may not be mapped as only one unique path in the middle, but instead it can be divided into more than one possible path from which employees can select only one to follow as their preferred route. Therefore, and to increase the user-friendliness of the navigation process, large corridors can be easily mapped as multiple rows and columns while assigning nodes to each of their intersections. This would allow a more precise and consistent routing (replacing "vibrant" location readings by a more stable node detection) through navigation while keeping a good factor of approximation. The corridor section with a wider space between two shelves can be abstracted like the one shown in Figure 13.

- Displaying the navigation route in UI:
  The node concept also provides a simple option to display direction markers on the map for the actual navigation route that an employee can follow. Arrows can be shown to direct the employee from node to node until destination. This allows using a simple set of graphics and maintains a clear and intuitive design. The final result of the navigation route display could look like the one shown in Figure 14.

4.2.2 Task Analysis Diagrams

The design thinking process is often employed as a standard practice in UX design to define and anticipate problems that might intercept system users ([261]). This means being able to clearly identify and articulate problems in the user experience so that you can begin to target them effectively and generate great ideas on how to solve them. Task Analysis ([117]) is the main activity that UX designers should consider during the problem analysis and definition. If this activity is performed correctly, it can help not only to identify opportunities to improve the UX of the system but also to generate some preliminary ideas of how to address the defined challenges.

Task analysis should be considered particularly during the "define" phase of the design thinking process. Usually, the analysis results are delivered in the form of a diagram that explains the steps a user should follow in order to accomplish the task. In this diagram, you can depict the actions taken by the users (or the system) to help them achieve their goals. Once these steps of how to accomplish a task are organized and ordered logically and coherently, we can have then a closer detailed look on how to better adapt the system to employ additional user support (e.g., to automate some actions

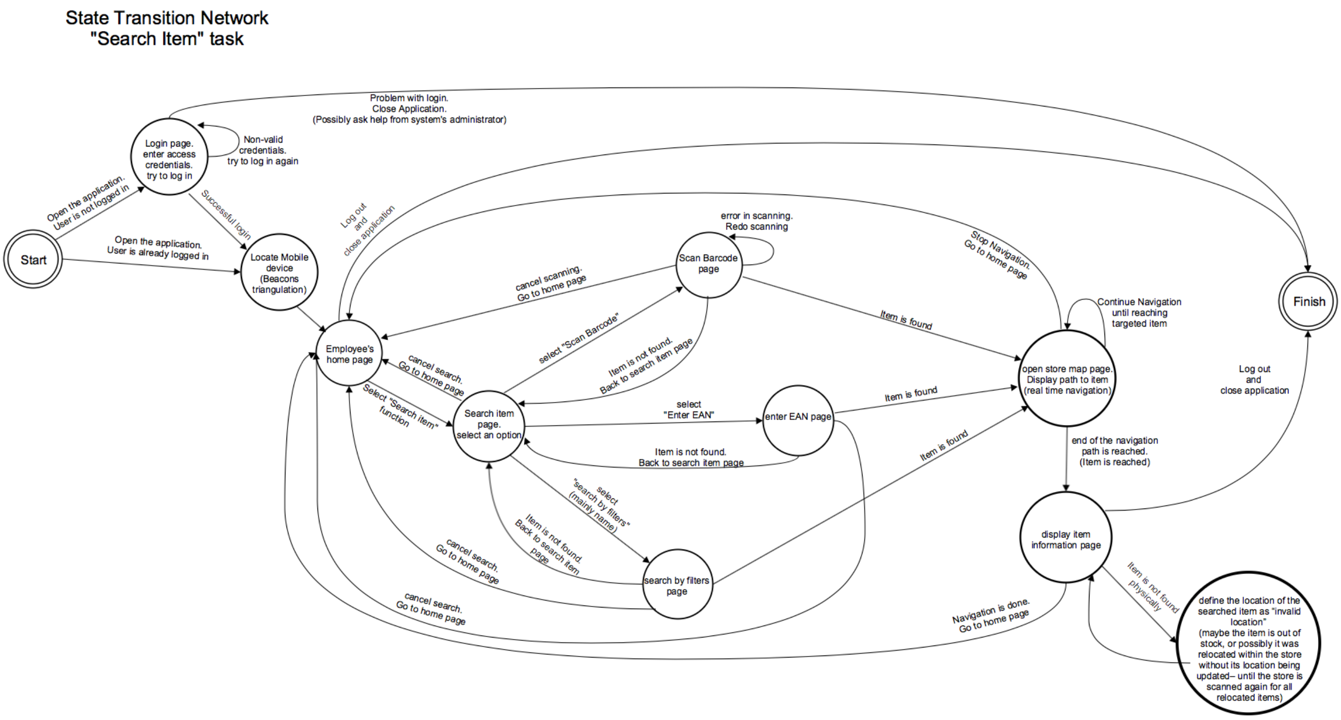


Figure 15. STN diagram of the Search Item task.

of the task), or eliminate unnecessary steps in order to minimize the number of actions that a user has to undertake to fulfill a task.

Therefore, we have performed the task analysis process for our system's main tasks (the ones discussed earlier in Section 2.2.2 following our case study of GK software pick-&-pack order fulfillment scenario and requirements), including Search Item, Insert Item, Update Item, Remove Item, Check Profile. We have presented the results of the task analysis using the State Transition Network (STN). Figures 15, 71, 72, 73, and 74 show the corresponding STN diagram for each of the five mentioned system tasks in the same order.

4.2.3 Data Model

The data model of the system should provide a good way of representing and storing all the map's relevant data. The main considerations that should be included in the data model design are:

- To be able to easily retrieve the map information and correspondingly easily render the map view.
- To be able to easily access the location of a specific item within the retail space map.
- To be able to support the dynamic location detection of the navigating employee in the realtime by using approximation (further information about possible navigation and routing techniques and approximate location detection are provided in Section 4.2.1).

Figure 75 shows a possible design of the system's data model. Besides, the corresponding Entity-Relation (ER) model is shown in Figure 76. This model clarifies the relations between the different entities illustrated in the data model. From this ER model, we can see that each retailer will be assigned a specific map. This map might contain many related buildings, but each building should belong to only one map. Additionally, each building might consist of many related floors,

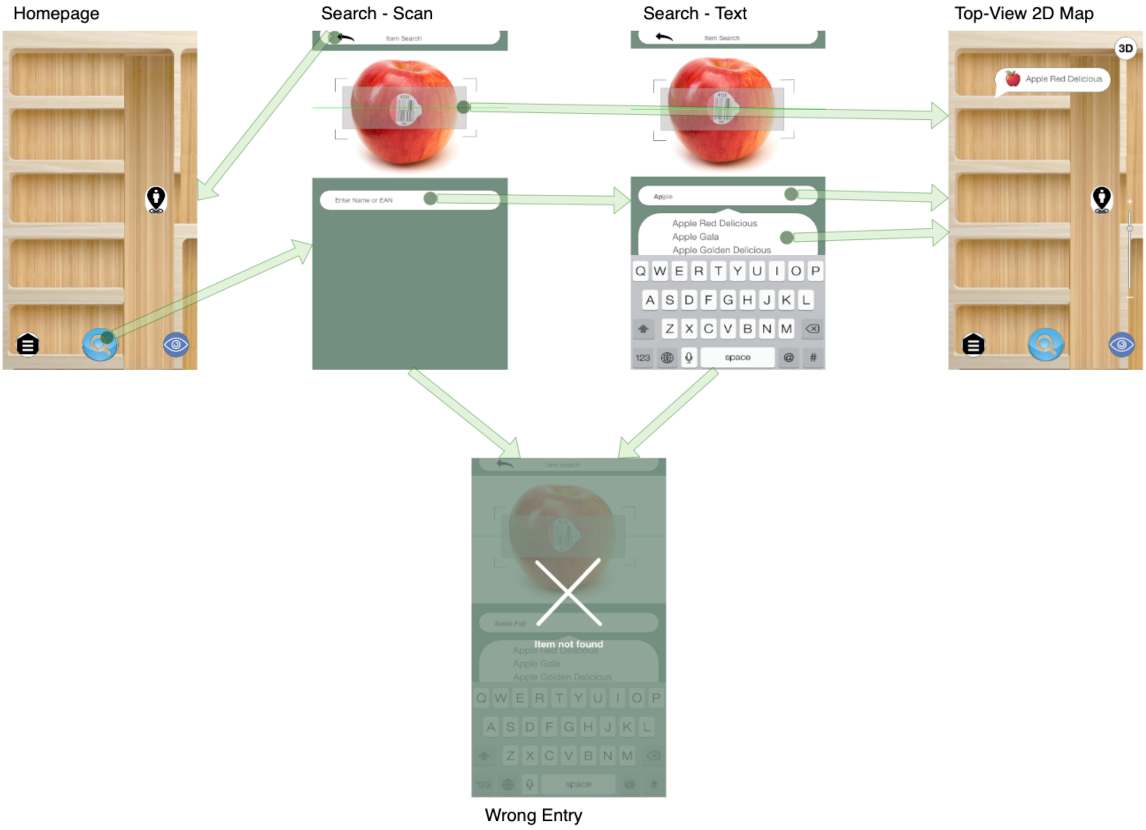


Figure 16. First set of the wireframes views for the system's front-end mobile application.

but each floor should belong to only one building. Further, each floor can have many shelves and installed beacons, but each shelf and beacon should belong to only one floor. Furthermore, each shelf can contain many levels, but each level should belong to only one shelf. Moreover, each level can contain many items, but each item should be placed on only one level in a shelf (at any given time).

In addition, the remaining area of each floor, after defining related shelves inside that floor plan, will be assigned to nodes. Each defined node should belong to only one floor. This node can represent the last/current active position of an employee in the floor plan. Also, each node can represent the position from which an item can be picked by an employee (which is actually the closest node to that item). To create paths between nodes, we assign edges to each node. These edges will link all the nodes together from all directions. Therefore, in a rectangular floor map, each node can be connected with up to eight edges (corresponding to the maximum number of surrounding nodes from all the eight directions), while each edge is connecting exactly 2 nodes. As discussed in Section 4.2.1, this will be important to provide the path suggestion feature especially in our case of pick-&-pack orders where usually an employee starts navigating through a specific path from an initial node until reaching the destination node from which an item can be picked.

4.2.4 Wireframes

After analyzing the main tasks of the system, we proceed to build the possible views of the wireframes design for the system's front-end mobile application, while following the correct and complete state transitions for each task. In order to achieve this, we used the Adobe XD software application, which provides the possibility to produce an interactive click-through view that simulates the real proposed prototype.

The first set of wireframes views are shown in Figure 16, where the "Search Item" task is explained. It starts with the main homepage view (also called the landing page) that contains the map of the smart retail space (e.g., store, warehouse, etc) while showing the current location of the navigating retail employee within this map (as resulted from the localization module of the system), who is currently holding the smart mobile device and using the front-end mobile application. At the bottom of this homepage view, there is a list of icons for the available systems tasks and functionalities provided for the retail employee to perform. In this main view, the employee can start with the first main task of searching for an item by selecting the search icon at the bottom of the page. After doing so, the view will be redirected to the search-item page where the available search options are shown. These search options can either be searching an item by scanning its barcode or typing manually the item's EAN. If an error occurred while scanning, the employee will be asked to redo the scanning again or just using the alternative search-by-EAN option. If the item is not found, the system will inform the employee about this, and then will be redirected to the homepage view to possibly choose a different task to perform. Otherwise, if the searched item is found, the retail space map view will be displayed while presenting the employee's corresponding current location on the actual map together with that searched item location pointed by its both symbol and name. While the employee is navigating the retail map heading towards the searched item, her location will be updated dynamically on the map in realtime (this navigation can be supported by displaying a specific route to follow as discussed in Section 4.2.1).

The second set of wireframes views are shown in Figure 66. This figure continues to elaborate on the related views to the "Search Item" task after successfully searching for a specific item in the system and displaying its location within the retail space map. While the employee approaches the shelf where the searched item is located, the "3D" icon can be clicked, and therefore, a view of the corresponding shelf (i.e., the exact shelf and all its levels including the one that contains that searched item) will be displayed to easily identify the item's location precisely within the shelf. The employee can switch back to the top-view localization of the item within the retail map by clicking "2D". In both "3D" and "2D" views, the employee can similarly click the item symbol and then a separate view with the detailed information about that item will be displayed including all other available options to manage that item.

The third set of wireframes views are shown in Figure 67. This figure continues at the view that displays the detailed information of the searched item while offering the employee to select one of the related available system tasks/functionalities to manage that item. The first available task is to declare the item location in the system as invalid by clicking the icon with an exclamation mark inside, where this is the case when the searched item is not physically found at the mentioned location on the retail map and that could happen due to many reasons (e.g., item is out of stock, item location was changed without being updated into the system, etc.). In the second available task, the employee can update the item location by clicking the other available icon. In this case, the item's new location will be assigned the current location of the navigating employee within the retail map (i.e., the current node in the retail map where the navigating employee is standing at the time of the update will be referenced as the node from which an employee can pick that item later in the future). To accurately insert the updated location of the item, the system can ask the employee to identify the exact new shelf and level within that shelf on which the item is placed (can be done automatically by the system based on the current node of the navigating employee). Moreover, the employee can update other information about the item (e.g., price).

It should be noted that when the item information and/or location are changed (either invalidated or updated), a safety dialog will be displayed to the employee asking to confirm the chosen action before any changes will be actually committed and reflected in the system. Afterward, if the employee chooses to retract from the chosen action, the view will be redirected back to the previous view (i.e., the view displaying that item information before applying any actions/updates). However, if the employee proceeds and confirms to apply the chosen action, the view will be redirected to the home page view so that another task can be performed (while tracking and showing the employee's current location within the retail map).

The fourth set of the wireframes views are shown in Figure 68, where we proceed to explore the system functionalities from the starting point of our front-end mobile application (i.e., homepage page). Here the employee starts by clicking the menu icon at the left bottom, and upon this selection the application view will be redirected to the menu page where the employee can select one of the available system tasks to perform including inserting a new item, updating a pre-registered one, and viewing the list of items with invalid location. The last functionality is accessed by clicking on the exclamation mark icon, which in turn will redirect the employee to a separate view displaying the list of all items in the system with an invalid location (so that possibly further actions about these items can be notified or taken in the retail warehouse/store).

The fifth and last set of wireframes views are shown in Figure 69. This set continues discussing and explaining the other two available system tasks mentioned in the fourth set (i.e., updating and inserting an item). In order to perform any of these two tasks, the employee (upon clicking any of the two corresponding icons) will be redirected to the search-item view first, so that the item can be searched for in the system (either by scanning its barcode or entering its numeric EAN manually), and therefore we can check if it already exists in the system database to proceed accordingly. This means either identifying that item in the system first and then fetching its related information in case of performing the update task, or verifying that item as a new entry into the system database and proceeding to add further information about it. In both cases, the employee needs to confirm these actions of updating or inserting the item before the changes can be committed into the system.

To have a complete live experience about the whole prototype, an online interactive demo can be found at [20].

4.3 System Implementation

The system as pointed out in the architecture section (i.e., Section 4.1) will consist of a front-end mobile application communicating with the smart connected sensors (mainly the BLE beacons) of the IoT system that is embedded in the smart retail space, and a back-end server that provides various services for location detection and map configuration while maintaining the system database. These main parts of the system architecture are already shown in Figure 6, and the technical details corresponding to each part implementation are discussed in the following sections.

4.3.1 BLE Beacons Trilateration

This section of the system implementation will discuss the significant role of the BLE beacons in providing a cost-effective location detection feature and therefore the feasibility of the whole in-store navigation solution. The core challenge is how to get an accurate location detection initially when the mobile application starts running, and afterward while the employee starts navigating the retail space. In other words, the positioning of the employee should be technically implemented with acceptable accuracy throughout the whole navigation process.

- Beacons Type:

The first technical detail to be determined is the BLE beacons type. After some technical evaluation conducted by GK Software company, the using of "Estimote Beacons" is proposed [6]. These Estimote Beacons come with two different types; the first is the proximity beacons which are optimized for reliable entry and exit events (i.e., to a specifically defined proximity of the beacons) and they allow to authenticate presence, send contextual notifications, display proximity-based content, or create software automation. The second type is the location beacons, which were chosen as they better suit our in-store navigation system requirements, since they can locate employees, provide real-time position data, collect attendance data, or deliver way-finding instructions. All relevant information about beacons' power consumption, signal strength range, and possible transmitted information are considered.

In this context, the term "Beacon Region" should not be mistaken as a region in a geographical context. Instead, this term is defined as a certain distance around the beacon where its transmitted signal can be detected.

- Position Calculation:

Following the trilateration concept, a position can be determined with three points and their distances to the unknown point. Graphically, the problem can be illustrated as three circles in a plain that can intersect in a minimum of three points and up to a maximum of six points (depending on the related centers and radiuses of the three circles). The point that represents the center of these intersections should be found in the middle of this intersection-points cloud. Projecting this concept to our system, we will have beacons as the circles' centers and the employee location as the middle point of the circles' intersections. After determining this central point, we can determine the distance to each circle center, i.e., to each beacon. Therefore, since we know the beacons exact coordinates in the actual retail space map, we can easily calculate the employee's exact current location.

One important issue to consider is to apply a 2D transformation of the points before calculating the position. This is because, in the real world, our positioning problem will be addressed in a 3D rather than 2D space. In other words, the signal-transmitting beacons are not located at the same altitude as the signal-receiving smart mobile device assigned to the navigating employee (i.e., both the transmitting beacons and receiving mobile device are not on the same 2D plane in the actual 3D retail space). Due to this fact, the distance estimation should be calculated accordingly and a transformation into the same 2D plane is needed first before performing the distance calculation. Otherwise, inaccurate calculation results will be generated. For example, if a beacon is mounted three meters above the employee (e.g., installed on the floor's ceiling or the shelf's top), and the employee stands directly under that beacon, the actual distance in the 2D top-view plane should be zero meters while the real measured distance is three meters minus the altitude at which the employee holds the smart mobile device.

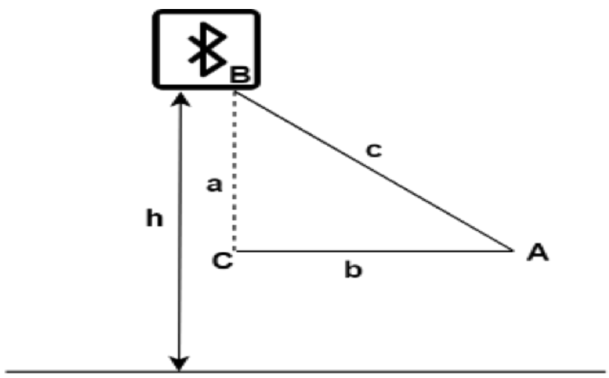
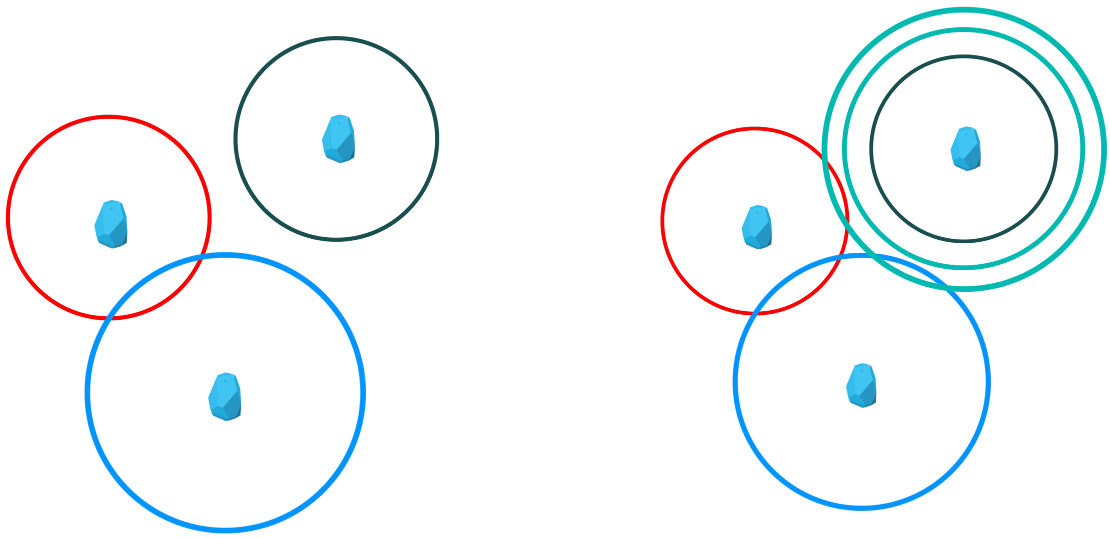


Figure 17. 3D-to-2D transformation to measure the trilateration-relevant distance to beacons in the 2D top-view plane.

This 3D-to-2D transformation can be explained using Figure 17. Since the smart mobile device (point A), the actual beacon position in 3D (point B), and the beacon top-view position in 2D (point C) form a right triangle, we can use the Pythagorean theorem to perform this transformation. Side "c" length of the triangle can be calculated using a mathematical formula based on the Received Signal Strength Indicator (RSSI) of the received BLE signals from the beacon. Side "a" length is the difference between the actual altitude of the beacon and the altitude of the mobile device (possibly a constant value that can be estimated according to the average height of adult humans



(a) (b)

Figure 18. The problem of non-intersecting BLE coverage circles calculated for beacons trilateration: (a) Non intersecting circles; (b) Suggested solution by increasing circle radius gradually until an intersection occurs.

with acceptable neglected differences). As a result, we can now easily calculate side "b" length which represents the actual distance between a beacon and the mobile in the top-view 2D plane.

- Non-Intersecting Circles:

A problem, which may sometimes occur, in the trilateration process is when the circles defined by the calculated distances to the beacons might not intersect (either one or even none of the circles) with each other, as shown in Figure 18a. One solution can be to manually adjust the calculated range distance of the non-intersecting circle/s (i.e., adjusting the calculated received signal from the corresponding beacon/s). In fact, the received beacon signals tend to show lower distances than the actual ones in reality (due to many reasons like BLE signal nature, signal propagation error, signal reflections, etc.) when the signal-receiving mobile is getting physically farther from that beacon. Therefore, the measured beacon distance can be increased step-by-step (e.g. 50 cm per step) until an intersection point is found, as shown in Figure 18b. This ensures easier and faster mathematical calculations, and might also improve the general accuracy as low distance readings are corrected equally. Additionally, in order to handle this issue, we have to use automatic beacon switching. In this case, a list of all the available beacons at the time of the signal scanning are ordered by their signal strengths, then the three beacons with the highest recorded values are selected. When the navigating employee changes position in the retail space, the corresponding received beacons signals will change, and therefore, the selected beacons for performing trilateration will change accordingly. This available-nearby-beacons list can be refreshed and updated on a periodic basis (e.g., every one second).

4.3.2 Front-End Mobile Application

Our proposed system provides a platform-independent front-end solution which is implemented using the open-source Ionic framework [16]. This free-access framework built on top of Apache Cordova [2] allows hybrid mobile application development which can be rendered into a web layer application that can run regardless the underlying native layer of the used smart mobile device assigned to the navigating employee. The front-end mobile application has to provide many functions for the in-store navigation system. These functions include the main items management tasks related to searching, inserting, updating, and removing items. This requires some textual visualization to select/type related data during each task. Besides, the scanner module is needed in the application implementation to allow users to scan barcodes in order to identify items correspondingly.

- Indoor Positioning Module:

Technically speaking, the indoor positioning module will be the major part of the in-store navigation system that should be considered carefully in the front-end application. In order to get this module implemented, we performed an initial analysis of the available technical solutions to communicate with the installed beacons in the smart retail space in order to perform the trilateration algorithm of the location detection. As a result, the "Cordova Plugin iBeacon" [3, 4] is proposed as a solution using the proposed available open-source framework to receive data from Estimote Beacons without using their cloud technology (i.e., providing an offline solution for navigation). This software plugin is built to mimic the iOS Core functionality for beacon communication. In general, the iBeacon plugin only encapsulates the functionality of a basic Bluetooth scanner, and reads the binary data from the signal and converts it into the iBeacon standard. For example, Apple established its standard for beacon-emitted transmissions which is called "iBeacon", where this standard defines how beacons can be identified and what data they are transmitting. Similarly, this proposed plugin makes it possible to use some standard functions by directing the calls to the native layer on the smart mobile device. On iOS devices, this can be done directly without any other libraries as the required functionality already exists. On Android devices, the plugin makes use of the "Android Beacon Library" which is an external library that is used for the implementation of this functionality. It will automatically be included by the plugin during the build process. The role of the Cordova Plugin iBeacon is shown in Figure 19.

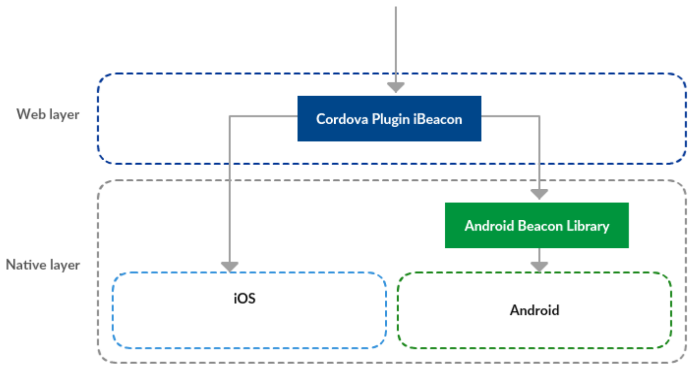


Figure 19. Cordova Plugin iBeacon role in providing a platform-independent implementation for communicating with beacons.

After communicating with the beacons, the application will read their identifiers from their transmitted stream and will calculate the distance from each beacon based on its received signal strength. On Android, the beacon library offers the option of the so-called Wildcard UUID which is used to uniquely identify a beacon. The major outcome of the beacon finding process depends on the availability of the locally stored list of beacons. From this list of beacons, the ones with the highest signal strength are selected, and then the positioning via trilateration algorithm is performed accordingly.

Since the beacons trilateration process can be affected by unstable error-prone RSSI readings (due to the nature of BLE signals and propagation errors), some alternative systems proposed to support the location detection process after applying the beacons trilateration by combining and utilizing the technologies embedded in the smart mobile device. The main idea is to track the initial location of employees using beacons trilateration and then enhance location detection dynamically during navigation using some mobile embedded technology combination and software algorithms (possibly using the embedded motion sensors of the mobile device like accelerometer, gyroscope, etc). However, we decided to drop this option since the promised reliability is not guaranteed and failure rates have been noticed in similar applications employing such motion detection in various mobile platforms (e.g., Andriod, iOS, etc). The location approximation using the node concept (as discussed in the map design section 4.2.1) provides a good solution with an acceptable location detection accuracy that suits our case study of retail in-store navigation.

Finally, The data about the beacons identifiers will be used to retrieve from the back-end server's database their exact location data (i.e., their x and y coordinates, exact floor, and altitude as installed in the retail space map). Then, the application can immediately identify where these closest beacons (in the defined proximity range) are located on the retail map with respect to the current navigating employee's location. This information will be accumulated with the other map-related data (including available shelves and their locations within the floor map, the available retail items in that floor and their locations on each shelf and the corresponding level, etc) by requesting them via HTTP calls from the system server. Therefore, the application can display the location of a searched item, for example, and how the employee is currently navigating the actual retail map while approaching that item's location.

- Barcode Scanning Module:

The barcode scanning module is an important part of the front-end mobile application. This module adds an important user-friendly aspect of the application by providing quick and simple identification of the retail items via only scanning their corresponding barcodes. Upon scanning the item's barcode, it will be interrupted as an EAN which uniquely identifies that item in the retail system. In order to implement that part, a survey of the available barcode-scanning frameworks has been conducted to select a suitable one that can be easily integrated into our system. A summary of the analyzed barcode-scanning frameworks is presented in Table .2. According to this survey, a good framework that is both free and can be easily integrated into our system's customized view is QuaggaJS. Therefore, this framework is selected to implement the barcode-scanning module of our system.

4.3.3 Back-End Server

The back-end server is implemented as an embedded web server of a Spring Boot web application following the MVC framework configurations. The server consists of two main parts: the first part is the system database which is implemented using MySQL database, and the second part is the available services that react to data requests/pushes by fetching/uploading data from/to the system database. These services (as mentioned in Section 4.1) are the location service and the map configuration service. Both services (and others to be added later if necessary) are implemented using REST while transmitting the data using JSON format. Each service will be assigned a REST controller that will handle the related requests of each service and fetch/upload the corresponding data by communicating with the database connector. All these requests/pushes from/to the database are handled accordingly. The proposed implementation of the back-end server can be seen in Figure 20.

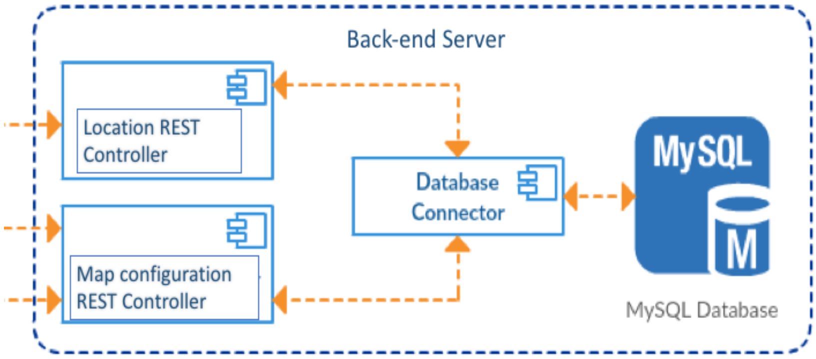


Figure 20. Back-end server implementation.

5 Evaluation

After implementing a prototype of the system following the discussed architecture in Section 4.1 and the suggested design in Section 4.2 while covering all parts presented in Section 4.3, a user study evaluating the UX of the system and the provided digital service is conducted. In this section, we describe the design and details of the conducted empirical study. It contains an exploratory experiment to observe users (i.e., retail employees) behaviors and interactions while using the in-store navigation system that provides the digitalized localization service in a smart retail space for the scenario of handling pick-&-pack orders. In particular, this study is performed as a controlled experiment that measures various case-related usability parameters (e.g., location awareness) and measures (e.g., navigation time to a searched item), and the results are analyzed to validate good usability of the proposed system. The selected tasks of the experiment are chosen carefully to reflect on the actual use cases of the system and reveals its usability features and characteristics. In other words, it focuses specifically on how the system can facilitate the items collection process for the pick-&-pack order fulfillment within the retail space while possibly doing other retail management tasks (e.g., inserting new items).

Overall, the evaluation analysis follows a mixed-method approach combining quantitative and qualitative measures, and the measured variables in this experiment are related but not limited to location awareness, learnability, perceived ease of use, perceived usefulness, trust, satisfaction, etc (other possible measurable UX-related aspects are already mentioned and detailed in Section 2.1). Besides, widely accepted models like TAM as well as the customer experience research in the retail context can help to assess the experiential aspects of our system and explore the interdependencies between its constructs that lead to positive usability experiences that drive the required digital service innovation. The collected feedback of such evaluation studies is meant to be utilized for a strategic design and enhancement of similar user-oriented technology-based innovative digital services.

In our conducted observational study, twelve participants who are mainly employees from the Innovation&Research department at GK Software SE with a good familiarity with retail processes and pick-&-pack orders were invited to perform this experiment at a dedicated part of the company building. This part is the company retail lab that constitutes of many retail-like floors which have many repeated features with a general lack of clear landmarks. After performing the experiment, participants' behaviors were analyzed using different metrics. In this experiment, participants were asked to use the in-store navigation application to perform the predefined list of tasks under a laboratory environment setup that simulates a smart retail space (for our defined case study, a retail-like floor with distributed retail shelves and installed IoT objects including BLE beacons should be suitable). Afterward, participants were asked to provide overall feedback through sets of open-ended and closed-ended questions, based on which statistical and analytical diagnoses were performed.

The following of this section is divided into four main parts. Section 5.1 presents the goals of the conducted study. In Section 5.2, we introduce our set of hypotheses regarding the proposed system. In Section 5.3, we discuss the design and execution details of the performed experiment including the experiment procedure, the participants' information, the set of selected tasks, and the user questionnaires design. Finally, we illustrate in Section 5.4 the different metrics we used to analyze users behaviors while using the digitalized localization service of our in-store navigation system.

5.1 Goals

Goals of our observational evaluation study are:

- To observe the participants (who represent the actual target users, i.e., retail employees) behavior while using the digital in-store navigation system and the related digitalized localization service to accomplish some tasks in the context of pick-&-pack orders fulfillment under our retail-like laboratory environment setup.

- To investigate whether the implemented system and the provided digitalized localization service helped participants to complete those defined tasks by reducing needed physical and cognitive efforts.

- To analyze other usability factors (both qualitative and quantitative) of the implemented system and the digitalized localization service that provide positive UX, and therefore, bring required service innovation.

- To assess and compare the added-value brought by the implemented user-centered digitalized localization service with the experience of basic naive non-localized digital maps (e.g., presented as a digital image of the floor layout) in terms of improvements in employee navigation and location awareness within the retail space.

5.2 Hypotheses

We hypothesize that providing retail employees with a user-centered digital in-store navigation system will add a satisfactory and positive UX to their navigation and retail space exploration. In particular, it will support location awareness while fulfilling pick-&-pack orders and help them to identify and reach items locations easily within the retail space. Moreover, employees can easily perform other items management tasks since the provided digital system offers efficient items processing (e.g., inserting, updating, etc.) throughout navigation. Consequently, the employees' understandability of the retail environment and work productivity will be increased. To summarize, we present the set of studied hypotheses in our observational usability study by analyzing the participants' behavior while using the implemented digital in-store navigation system.

- **Hypothesis 1:**
  - The Task duration time is reduced.

- **Hypothesis 2:**
  - Employee's location awareness is enhanced.

- **Hypothesis 3:**
  - The proposed system requires more learning effort.

- **Hypothesis 4:**
  - The proposed system is easier to use.

- **Hypothesis 5:**
  - The proposed system provides more useful functionalities/features to perform related retail tasks.

- **Hypothesis 6:**
  - Employees better trust the system functionalities and the provided information (e.g., localization information, items information, etc.).

- **Hypothesis 7:**
  - The proposed system's functionalities/features are considered more satisfactory and appreciated by employees.

5.3 The Evaluation Experiment Procedure

Based on the identified goals and hypotheses, the user evaluation study is designed as an observational and exploratory evaluation. Kulyk, Olga, et al. [189] present a set of important questions to be answered before starting the evaluation experiment:

- ***What to start with?*** The first question to be answered, as it defines the experiment goals.

- ***With whom?*** Preparing a detailed description of the target users profile (retail employees in our case study). Knowing whether users will work as a single user in the retail space, or in a multi-user retail environment. Understanding if it is necessary to divide users into different categories (e.g., some employees responsible for handling retail management processes in one category, while other employees responsible for fulfilling pick-&-pack orders in another category). Checking if users can take the same role or different roles (e.g., junior, senior, manager, etc.) depends on the system requirements and related experiment goals.

- ***The evaluation tasks and metrics.*** Tasks have to be realistic, motivating, and engaging the domain experts. The common usability measurements in the empirical evaluation are user performance, behavior, and attitude.

- ***When and where?*** Estimate the time for the experiment preparation and performing. Choosing the experiment environment is also important.

- ***How to avoid being biased?*** For instance, be aware of alternative evaluation methods that can be applied.

- ***Ethical issues:*** Ensure the users' privacy.

- ***Data analysis:*** Choose the appropriate method to analyze the collected data, such as applying appropriate statistical techniques or representing data by graphs and plots.

- Decide ***When to stop evaluating:*** Constraints of time and budget usually determine when to stop.

- Finally, ***from evaluation to UX design guidelines and gained feedback improvements.***

In our study, we tried to answer most of these questions before evaluating our collaborative environment. Answers are included in different sections. We briefly describe our answers to the above-mentioned questions in Table 2.2.

5.3.1 Conducting the Experiment

To ensure that the participants had the basic knowledge about the test platform before starting the experiment, every participant was given a 10-minute introductory session about the digital in-store navigation system and its provided functionalities/features for handling retail management processes. During this session, we described all the functions of the interface and how it can be used while navigation. Then, we allowed participants to explore the application freely for 10 minutes before the test so that they could try working with the system and feel familiar with all its functionalities/features. Besides, we allowed participants to ask any further questions about the system during the training session (and also during the experiment in case of any accidental technical issues).

First, participants were administrated questionnaires asking about their age, gender, the field of study, familiarity with retail management processes, nationality, and inquiring about their experience with any similar digital in-store navigation systems (more details in Section 5.3.2). After this introduction, participants were briefed on the tasks given a printed document reference for each participant. As part of the briefing, we described the different types of available interactions to perform the same task (e.g., inserting a new item via barcode scanning vs. manual EAN typing) as supported by the interface.

Since this evaluation study is intended to compare two conditions: the digitalized localization service of our system and the basic non-localized digital maps (e.g., a digital image of the floor layout), we asked the participants to perform two similar experiments with the same set of tasks for each condition using a within-subject design (i.e., all invited participants try both conditions) while randomizing the order of conditions to start with and the selected floor layout to avoid bias. Therefore, we prepared two retail-like floors with different layout and shelves organization so that every participant could perform the same set of tasks for each condition in a different layout. Moreover, It should be noted that none of the participants was familiar in advance with any of these floor layouts. Afterward, each participant was invited alone (i.e., one by one) at one of the floors to perform the defined tasks in one selected condition, and then to perform these tasks in the second condition at the other floor.

Participants were allowed to accomplish the two defined tasks within a 20-minute maximum time per session (more details about these tasks in Section 5.3.3). This maximum time for accomplishing a task was estimated based on the maximum route length a participant would navigate in the chosen experiment floors (i.e, considering the maximum navigation time needed), and also considering the time needed for doing other activities during a task (e.g., inserting a new item's information into the digital system while placing it physically on the defined shelf). After the test, we asked each participant to fill in two questionnaire forms. The first was a closed-ended questionnaire form with seventeen questions that offered five different answer options based on a 1-to-5 Likert scale which is scaled from 1 (strong disagreement) to 5 (strong agreement) to show the degree of agreement with each question from the participants perspective. The second form was an open-ended questionnaire form with three general questions. The experiment was performed under laboratory conditions, with a maximum time frame of 80 minutes per session (including questionnaires answering). However, each session lasted around 60 minutes on average.

Participants used the in-store mobile application in one experiment and the basic non-localized digital map (possibly using a pdf or image viewer) in the other experiment, which are both installed on a smart mobile device (in this study, we used iPhone 8 plus with 5.5-inch screen size). In the case of using the non-localized digital map, the provided digital image was marked with an indicator to the destination location point, which can be represented as a labeled symbol of the searched

Step	Description
Define the experiment goals and hypotheses.	The main goal of our study is to investigate usability parameters of the proposed digital in-store navigation system (see Section 5.1), and the related hypotheses discusses the advanced UX facilitated by the system compared to basic non-localized digital maps (see Section 5.2)
Choose the experiment environment.	We decided to apply a semi-controlled experiment; thus, we conducted our study in a laboratory environment that constitutes of a retail-like floor layout with distributed shelves and items.
Specify the evaluation and the analysis methods.	We measured different quantitative (e.g., time to perform tasks) and qualitative (e.g., user satisfaction) parameters.
Estimate the experiment time.	We estimated the time needed for preparing and conducting the experiment.
Design tasks.	We designed realistic tasks, which cover the actual use cases of the system (mainly while fulfilling pick-&-pack orders and doing other retail management tasks) and reveals its usability features and characteristics (see Section 5.3.3).
Design the questionnaires.	We designed both open-ended and closed-ended questionnaires considering the variables we want to measure (see Section 5.3.4).
Invite participants to perform the experiment.	We invited participants to conduct our experiment using a within-subject design (see Section 5.3.2).
Ethical issues.	We ensured participants privacy, which means their personal preferences will not be associated in public reports. All background details about participants remain confidential, as they contain very personal data. We explained to participants the general goal of the study and asked their permission for any collected/captured information/pictures during the study. We assured them that their personal data will not be published.
Analyze the collected data from the experiment.	We analyzed the collected objective and subjective data using different metrics by observing patterns, calculating the average, statistical analysis, etc. (see Section 5.4.)
Present the results.	Our findings from the observational study and the collected responses through the questionnaires are presented and discussed. The final results are discussed with respect to our hypotheses (see Section 6).

Table 2.2. The evaluation experiment general procedure.

Step order	Description
1	Collecting participants information.
2	Training: Providing participants with the platform tutorial. Train participants how to use the in-store navigation application.
3	Introduction to the study.
4	Presenting the required set of tasks.
5	Conducting the test: Participants carried out the experiment.
6	Filling the closed-ended questionnaires.
7	Filling the open-ended questionnaires.

Table 2.3. The test procedure description.

item (similar to the presentation provided in the in-store navigation system). However, participants start location was not predefined, and therefore, not marked on the digital image. Participants were asked to perform the explained tasks and to act naturally within the retail-like space. They were particularly told to verbalize their thoughts and to talk freely while performing the given tasks. They were also asked to report any sudden technical problem they might face during the use of the system. During the experiment, the same trainer monitored the experiment in order to avoid any difference in the given material and the training session for all participants. Moreover, their interaction with the system during the test was observed for the later analysis. During and after the experiment, we collected data to be analyzed so we can check our hypotheses. Table 2.3, shows the experiment's followed procedure.

5.3.2 Participants

In the conducted observational experiment, 12 participants were chosen anonymously from the Innovation&Research department at GK Software SE. These participants were generally employees who are familiar with retail processes and pick-&-pack orders. They have different specialization background as described in Table 2.5, and therefore, they have normally different expertise. Besides, the users have diverse cultural backgrounds as shown in Table 2.4.

Participants took part in our experiment separately (i.e., one by one). We scheduled the experiment sessions using the doodle poll, distributing 24 sessions (so that each participant conducts two sessions, i.e., one session for each condition following the within-subject design) in different times within two weeks according to the participants' availability. In each day, we conducted an average of two sessions where each session lasted for an average of one hour. Out of the 12 participants, 7 were male participants and 5 were female participants. The age of participants ranged from 21 to 54 years with a median of 34.

We asked participants to comment if they have any experience with similar digital indoor-navigation mobile applications before conducting the experiment. We found that none of the participants had such similar experience of using digital indoor navigation assistance before the experiment. On the other hand, a questionnaire form was used for knowing the background of each participant in using digital services (and mainly through smart mobile devices) in retail before

Participants	Frequency	Percentage
German	3	25%
Pakistani	3	25%
Palestinian	2	17%
Syrian	2	17%
Colombian	1	8%
Jordanian	1	8%
Total	**12**	**100%**

Table 2.4. Participants cultural background.

Participants	Frequency	Percentage
Computer Science & Engineering	5	41%
Business Management	3	25%
Marketing	2	17%
Other fields of study	2	17%
Total	**12**	**100%**

Table 2.5. Participants specialization background.

starting each session. Most of the participants (i.e., around 67%) commented that they have a moderate experience using some digital services to handle some retail management processes (e.g., inserting a new item) via smart mobile devices, and 8% commented that they have not used any digital services deployed on smart mobile devices, while the remaining 25% responded that they have used such digital services from time to time. In our experiment, almost all participants had considerable experience using general mobile interfaces before the experiment. To ensure a relaxed atmosphere through the experiment, they were informed that the experiment is not graded and no other person will be watching them during the experiment time. Also, participants did not know in advance the trainer who presented and monitored the experiment.

We collected the mentioned relevant basic information (e.g., gender, age, any form of color blindness, etc.), in order to analyze the results from different perspectives. We asked participants to fill this part of the questionnaires before starting the experiment.

5.3.3 Study Tasks

We designed the test scenarios carefully, by including parallel and joint tasks (e.g., in order to update an item, you need to search for it first). We designed tasks for participants to choose a digital view independently (e.g., inserting an item via barcode scanning or alternatively typing its EAN manually) in order to fulfill the task requirements. In general, tasks were focused to observe how participants interact simultaneously with both digital (through smart mobile devices) and physical (through the physical location between shelves) views while navigating in runtime. The given tasks provided different types of interactions with both views (e.g., usage of the digital scanning feature to identify a physical item, checking the digital 3D view of a shelf to locate an item physically in the floor layout and the actual corresponding shelf). The defined scenarios for our study tasks described possible interactions with the interface that simulate the user needs while interacting in a real-life situation (i.e., fulfilling pick-&pack orders, performing retail management processes, etc.).

In total, the following two tasks were selected according to the provided system tasks (see Section 2.2.2) with the help of the domain expert. Each task had a number of closely connected steps, and both tasks are correlated to simulate a coherent experience for retail employees while performing related retail tasks.

Task 1: Inserting a new item into the retail space.

- ***The Goal:*** Task 1 starts by enabling participants to navigate through the retail space while getting support from the available digital view on their assigned smart mobile device (either using our digital in-store navigation system in one condition or using the non-localized digital map in the other condition). The aim is to reach the defined location quickly and easily (and therefore saving time and effort) to place a new item on the corresponding shelf while inserting it digitally as a new entry in the system. During this task, participants first interaction with both digital view (via the smart mobile display) in parallel with the physical view (throughout the corresponding physical route in the retail floor) are observed together with their interaction speed with the system and the interface.

- ***Description:*** The task requires to physically insert a new item in the retail floor and place it on a specific shelf related to that item category, and then correspondingly insert it (including all its related information, i.e., EAN, name, category, price, etc.) digitally in the retail system.

- ***Steps:*** The interaction pattern with the system for deciding the destination location (i.e., desired location to insert the new item) starts as the participant enters the related retail floor and uses the provided digital support (as we mentioned earlier, either using our digital in-store navigation system in one experiment or using the non-localized digital map in the other experiment). The participant then views the provided digital layout of the retail map on the assigned smart mobile device in order to match her location (i.e., localize herself) physically in the actual floor map, and understand in which part of the floor (southern, northern, eastern, western, or central zone, close to which shelf, etc.) she is currently located. This localization process continues as the participant navigates the space moving towards the destination location. Once the participant arrives at that location, she can place that item there at the exact level of the destination shelf. Consequently, this new entry should be inserted digitally into the retail system using a specific portal. It should be noted that this portal is embedded into our proposed digital in-store navigation system while in the condition of using the non-localized digital map the participant should open a separate dedicated application. In both cases, the participant should fill all the item-related information (i.e., EAN, name, category, price, etc.), which are provided in advance before the experiment, and submit them to the system. Once the new item is submitted into the system, other users can view it too. If the participant notices that she mistakenly submitted some wrong information about the new item, she can immediately correct the information by updating that item. The system allows many users to interact with it at the same time reflecting more realistic interaction in the retail context. This task helps to observe participants when utilizing the system functionalities and interface, and how they perceive location awareness using the provided digital support in each condition.

Task 2: Updating a pre-registered item and picking up another one from the retail space.

- ***The Goal:*** Task 2 is aimed to search the retail space for 2 specific items; one to update its information, and the other to pick it up. In doing so, participants need to navigate through the retail space for reaching each of both items while getting support from the available digital view on their assigned smart mobile device (either using our digital in-store navigation system in one condition or using the non-localized digital map in the other condition). During this task, participants interaction with both digital view (via the smart mobile display) in parallel with the physical view (throughout the corresponding physical route in the retail floor) are observed together with their interaction speed with the system and the interface.

- ***Description:*** The task requires to update a pre-registered item and pick another one from the retail floor. For the first item to be updated, this includes updating an item location by placing it on another specific shelf related to a specific category or requirement (e.g., items on sale) while updating other item information (e.g., price). The new item location and information should be then correspondingly updated digitally in the retail system. For the second item to be picked up, this requires to search for that item location and navigates towards it.

- ***Steps:*** Task 2 starts immediately after accomplishing Task 1, and the interaction pattern with the system for deciding the first destination location, i.e., either the location of the item to be updated or the location of the item to be picked up (based on which one is closer to the participant then), starts as the participant continues navigating the related retail floor while using the provided digital support (as we mentioned earlier, either using our digital in-store navigation system in one experiment or using the non-localized digital map in the other experiment). The participant is continuously viewing the provided digital layout of the retail map on the assigned smart mobile device in order to match her location (i.e., localize herself) physically on the actual floor map, and understand in which part of the floor (southern, northern, eastern, western, or central zone, close to which shelf, etc.) she is currently located. This localization process continues as the participant navigates the space moving towards the first destination location. Once the participant arrives at that location (assuming it is the location of the item to be updated), she can pick up that item. Afterward, the participant can reassess her next navigation destination, i.e., either to place this item into its new desired location, or pick up the other item from where it is located (again based on which one is closer to the participant then). The participant moves towards the closer destination (assuming again it is the new desired location of the item to be updated) and places the item there at the exact level of the destination shelf. Consequently, the updated information of that item (i.e., the new desired location, new price, etc.) should be submitted digitally into the retail system using a specific portal. It should be noted that this portal is embedded into our proposed digital in-store navigation system while in the condition of using the non-localized digital map the participant should open a separate dedicated application. Once the new updates are submitted into the system, other users can view it too. If the participant notices that she mistakenly submitted some wrong information about the updated item, she can immediately correct this information and resubmit it again. Finally, the participant can move to the last destination in her task and pick up the other item, and therefore, accomplishing the last step of this task. During this whole task, the system allows many users to interact with it at the same time reflecting more realistic interaction in the retail context. This task helps to observe participants when utilizing the system functionalities and interface, and how they perceive location awareness using the provided digital support in each condition.

To conclude, both of the two tasks designed for our experiment include performing and using all main functionalities of our digital in-store navigation system (i.e., inserting, searching, and updating items) to simulate real scenarios of handling pick-&-pack orders while observing the easiness in which users can perform these tasks and navigate through the retail space to achieve required goals. Further, participants performance while interacting with the system in both conditions (i.e., when using our digital in-store navigation mobile application vs. when using non-localized digital map) can be inferred and compared. Multiple users can easily perform these tasks simultaneously. The nature of test scenarios was kept simple to reduce the complexity of observation analysis while still reflecting the corresponding real use cases. In general, this experiment is directed towards describing how retail employees would work using our system, rather than in the actual outcome from applying the tasks. In other words, this study focuses on employees interactions and usability measures while performing the tasks as a main indicator for the enhanced UX, and therefore, for realizing the promised innovation of our system.

5.3.4 Study Questionnaires

In order to design a questionnaire form, there are several questions and responses formats to choose from. Choosing the appropriate format, which suits the goal of the research study, helps the users to answer clearly and the researchers to analyze correctly. We used the Likert scale in our study, as it is a widely used rating scale for evaluating user satisfaction [264]. We used a mixture of negative and positive questions, which helped us to check the users' intentions [264].

Participants responded to closed-ended and open-ended questionnaires. In the closed-ended questionnaire, the aim is to ask participants how much they agreed or disagreed with specific statements. The answers to the closed-ended questions describe participants satisfaction and their perception of how they performed during the tasks. Answers to these closed-ended questions gave participants a fixed set of alternatives to choose from, which can be treated quantitatively, and therefore, the collected results can be analyzed statistically using different related analytical tools like ANalysis Of VAriance (ANOVA). The answer to each closed-ended question was given as a scale between 1 to 5:

- 1: Indicates that the subject strongly disagrees
- 2: Indicates that the subject disagrees
- 3: Indicates that the subject neither disagrees nor agrees
- 4: Indicates that the subject agrees
- 5: Indicates that the subject strongly agrees

In the open-ended questionnaires, participants commented in a free text on questions about their opinions concerning the system functionalities and usability features. Moreover, we asked them to rate the system, provide suggestions and feedback. The trainer was with the participants when they filled the questionnaires, in order to clear any question and resolve misunderstandings or ambiguities.

5.4 Metrics

In this study, several types of metrics were measured and diagnosed. First, each session was fully analyzed to study participants behavior during navigation in both conditions (i.e., using our digital in-store navigation system and using basic non-localized digital maps) excluding the time spent on introduction, training, and filling in the questionnaires. Besides, total task duration time was calculated to infer related participants performance in each condition. On the other hand, different usability parameters were analyzed using the closed-ended and open-ended questionnaires. During sessions, participants were allowed to ask the trainer about any confusion or difficulty they faced, and they were encouraged to verbalize their thoughts while performing the tasks.

5.4.1 Observing Visual Attention During Navigation

We started the analysis by observing participants behavior all the way through the experiment while writing a high-level narrative of what happens. We consider to note down any potentially interesting events. However, interesting events depend on what is being observed and in which context. For our scenario of retail processes management and orders fulfillment, observing how participants use the provided digital system on their assigned mobile device to support them while performing the tasks is considered important. In this context, activities such as participants' visual attention would be appropriate to be noted and written down. In analyzing such data, the focus is on the patterns and anomalies in participants' routine interactions. This requires in-depth microanalysis of participants interaction with both the digital and physical worlds surrounding them.

In the light of these analyses, it should be also noted that a successful technological augmentation of a task or process depends on a delicate balance of users interactions with both digital and physical worlds of the smart space while employing appropriate structured technology. In other words, technologies which provide little or no overhead while performing or switching between activities would allow users to transition easily between those activities, focusing instead on accomplishing tasks. In such smart spaces, interactive mobile systems appear to be a good digital solution in helping users to get the needed information while working in the physical world. On the other hand, other factors could affect users performance such as the environment itself. Based on these considerations, the aim of our experiment is not to study directly the digital system interface only, as being the central concern of the interaction with the digital world of the smart retail space, but all the factors that influence the behavior of the system users while revealing its efficiency and their performance.

As an initial step of the analyses, we filtered each session for the time in which participants were working only on the defined tasks out of the session's total recorded time by excluding the time spent on "not-work" briefing, asking questions to the trainer during the experiment, interruptions, etc. The resulted task duration time was then divided into 2 main categories: navigation time and other-activities time. Navigation time is the time spent by a participant while navigating the retail-like floor to reach a destination location (e.g., location of a searched item, to-be-updated item, to-be-picked-up item, etc.) while performing a task. Other-activities time refers to rest of the time needed to do all other activities to accomplish a specific task (e.g., insert item information into the system, place an item on the destination shelf, update item information, etc.).

In this study, observing participants during navigation time helped us in collecting a wide range of raw data which is considered a rich resource and main indicator of participants performance. In particular, these observations of participants visual attention can be interrupted and coded to infer their performance, and therefore, to infer the provided digital system efficiency in supporting them. Hence, an appropriate categorization scheme is required to describe these observed codes of interaction. These physically-based codes are easier to identify during analysis compared to more socially-based codes, which rely on abstraction [47].

We categorized participants visual attention into 3 main categories/codes: the participant is looking at the mobile screen (also called "mobile-view"), the participant is looking at the surrounding retail environment (also called "surrounding-view" in which a participant can be looking at the retail floor, shelves, items on shelves, etc.), or the participant is looking at both together alternately (also called "alternate-view") as summarized in Table 2.6. It should be noted that a visual attention state is determined by a **predominant period** of at least five consecutive seconds and it is characterized by one of the mobile-view or surrounding-view visual codes. a visual attention state of fewer than five seconds in any of these two visual codes will be then considered as an alternate-view state. This predominant period was selected similarly to the period chosen to recognize the predominant gaze pattern of participants while observing them using collaborative digital systems as proposed in [172].

Finally, based on this proposed categorization of visual codes, we can analyze the navigation time of each session accordingly which results in a set of related visual attention states. We

Visual Category/Code	Description
Participant is looking at the mobile screen ("mobile-view").	A participant is looking at the mobile screen typically to view the provided information about her current location on the digital retail map.
Participant is looking at the surrounding retail environment ("surrounding-view").	A participant is looking at the surrounding retail environment (e.g., retail floor, shelves, items on shelves, etc.) to understand her current corresponding physical location.
Participant is looking at both together alternately ("alternate-view").	A participant looks at the mobile screen then looks at the surrounding environment alternately trying to match her understanding of location on the provided digital map of the mobile screen to the actual physical location in the surrounding environment.

Table 2.6. Codes describing participants visual attention during the navigation time of the evaluation experiment.

developed a state transition model to visualize how a participant switch between these states (i.e., mobile-view, surrounding-view, and alternate-view) as shown in Figure 21. All participants can start their navigation time in any of these states, then they can keep switching dynamically and freely between them until the end of their navigation. We assume the provided digital system to be efficient when participants spend most of the navigation time in the alternate-view state. This is because it indicates a flawless emergence of the participants with both digital and physical worlds simultaneously as they can easily understand, switch between, and correlate both views (i.e., mobile view and surrounding view). However, when the participants spend more time focusing on the mobile view or the surrounding view alone during navigation (particularly), then this can be inferred as confusion, lack of understanding, and failure to link both digital and physical worlds simultaneously, i.e., correlating the digital map on the mobile screen with the actual floor layout. Consequently, participants who spend more time in these two states (i.e., mobile view and surrounding view) tends to spend more total navigation time compared to those who spend more time in the alternate view to reach their destination location. This can be directly related to the proposed digital system efficiency and can be considered the main indicator of its users' performance. To sum up, correlating both digital and physical worlds in smart spaces is not a one-time effort but rather an ongoing procedure running in parallel with the fulfillment of the defined tasks and calls for other general required skills (e.g., problem-solving and decision making). Therefore, the constant switching between participants view states is expected, and maintaining an alternate view state generally implies good usability of the proposed digital system.

5.4.2 Post-Visit Questionnaires

Closed-Ended Questionnaire and Related ANOVA Analysis of Usability Measures

After participants completed the defined tasks for the both given conditions in two different sessions (i.e., using our digital in-store navigation system in one session and using a basic non-localized digital map in another), we asked them to rank their experience in the two conditions from worst to best according to six different criteria: location awareness, learnability, perceived ease of use, perceived usefulness, trust, and satisfaction. To do so, participants were given a closed-ended questionnaire to answer a set of questions related to each criterion. These answers were used to compare the UX of both conditions. In detail, the answers of the participants represent a normally-distributed sample of the total actual UX in each corresponding condition (assuming that selected participants

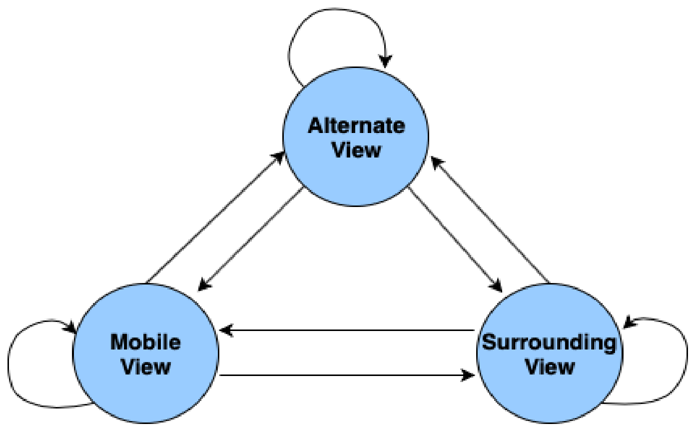


Figure 21. State transition model describing the changing states of participants visual attention during navigation time.

represent a normally-distributed sample of the population). Therefore, we can statistically compare between these two given conditions by comparing the collected samples (i.e., participants answers) of the related UX factors/measures in each condition. This statistical comparison can be achieved using ANOVA to compare the means of the collected two samples to test our hypotheses of UX as discussed in Section 5.2.

To sum up, we plan to run a single-factor ANOVA analysis for comparing each usability measure between both conditions, and therefore, testing every single hypothesis separately. It should be noted that the average task duration time (which is the average consumed time per participant to achieve the defined tasks) needed to test our first defined hypothesis is considered an important usability metric to compare between the given two conditions. This metric is not measured through questionnaires, but instead through observation (as we will discuss in the following). On the other hand, open-ended questions can help to understand measured UX dimensions, and possibly considering other usability measures by considering participants suggestions and feedback.

Task Duration Time As mentioned in Section 5.4.1, the first step of the analysis was to filter each session for the actual task duration time as performed by each participant correspondingly while excluding all the other time spent on "not-work" briefing, asking questions to the trainer during the experiment, and interruptions. Afterward, this time was statistically analyzed and compared (as an average time for all participants) in both presented conditions. This analysis was performed using single-factor ANOVA analysis where the task duration time is the variable factor that will be used to compare the two samples (i.e., using both above-mentioned conditions). Based on the ANOVA results, we can test our hypothesis that our proposed digital in-store navigation system requires shorter time to perform tasks in the context of pick-&-pack orders fulfillment and retail management processes.

Location Awareness This usability metric was measured by statistically analyzing and comparing the answers to the following questions in the closed-ended questionnaire for both presented conditions. This analysis was performed using single-factor ANOVA analysis for each question where the participants' answers (their value of agreement in 1-to-5 Likert scale) is the variable factor that will be used to compare the two samples (i.e., using both above-mentioned conditions). Based on the ANOVA results, we can test our hypothesis that our proposed digital in-store navigation system provides better location awareness while navigating the retail space to perform tasks in the context of pick-&-pack orders fulfillment and retail management processes.

- Q1: I managed to correlate my start location within the surrounding retail environment in the physical floor layout with the corresponding location on the mobile screen.

• Q2: I monitored closely the changes in my location while navigating the retail space.
• Q3: I didn't have problems in understanding my exact location (e.g., between or near which shelves) while navigating the retail space.

Learnability This usability metric was measured by statistically analyzing and comparing the answers to the following questions in the closed-ended questionnaire for both presented conditions. This analysis was performed using single-factor ANOVA analysis for each question where the participants' answers (their value of agreement in 1-to-5 Likert scale) is the variable factor that will be used to compare the two samples (i.e., using both above-mentioned conditions). Based on the ANOVA results, we can test our hypothesis that our proposed digital in-store navigation system requires more learning effort to perform tasks in the context of pick-&-pack orders fulfillment and retail management processes.

• Q4: It was easy to learn the system and its various provided functionalities/features including the sequence of steps to perform a task, the meaningfulness of the provided buttons and their icons, etc.
• Q5: It was easy to understand the provided content of the different views and their design (e.g., viewing items location in 2D/3D, viewing the detailed information of a specific item, etc.).

Perceived Ease of Use This usability metric was measured by statistically analyzing and comparing the answers to the following questions in the closed-ended questionnaire for both presented conditions. This analysis was performed using single-factor ANOVA analysis for each question where the participants' answers (their value of agreement in 1-to-5 Likert scale) is the variable factor that will be used to compare the two samples (i.e., using both above-mentioned conditions). Based on the ANOVA results, we can test our hypothesis that our proposed digital in-store navigation system is easier to use to perform tasks in the context of pick-&-pack orders fulfillment and retail management processes.

• Q6: It was easy to understand the provided location information of the system (e.g, directions and orientation), and therefore, to navigate within the retail space using the system.
• Q7: It was easy to use the provided functionalities/features of the system to perform retail management processes (e.g, insert a new item digitally into the retail system).
• Q8: Overall, The system was easy to use to perform the defined tasks.

Perceived Usefulness This usability metric was measured by statistically analyzing and comparing the answers to the following questions in the closed-ended questionnaire for both presented conditions. This analysis was performed using single-factor ANOVA analysis for each question where the participants' answers (their value of agreement in 1-to-5 Likert scale) is the variable factor that will be used to compare the two samples (i.e., using both above-mentioned conditions). Based on the ANOVA results, we can test our hypothesis that our proposed digital in-store navigation system provides more useful functionalities/features to perform tasks in the context of pick-&-pack orders fulfillment and retail management processes.

• Q9: The system provided more flexibility in reaching the destination location (e.g., understanding current orientation and different alternative possible routes) within the retail space and in performing the needed retail management processes (e.g., via different alternative possible methods to insert/update/search items) while performing the defined tasks.
• Q10: Using the system helped me to get a deeper insight into the retail space and its related processes.
• Q11: Overall, the system provided useful functionalities/features that helped me to accomplish the defined task.
• Q12: The system improved my overall performance while accomplishing the defined tasks.

Trust This usability metric was measured by statistically analyzing and comparing the answers to the following questions in the closed-ended questionnaire for both presented conditions. This analysis was performed using single-factor ANOVA analysis for each question where the participants' answers (their value of agreement in 1-to-5 Likert scale) is the variable factor that will be used to compare the two samples (i.e., using both above-mentioned conditions). Based on the ANOVA results, we can test our hypothesis that our proposed digital in-store navigation system provides its users more confidence and better trust regarding the system functionalities and the provided information (e.g., localization information, items information, etc.) to perform tasks in the context of pick-&-pack orders fulfillment and retail management processes.

- Q13: All the information provided by the system (e.g., localization information, items information, etc.) were authentic and correct.
- Q14: Overall, I trust using the system to finish the defined tasks successfully.

Satisfaction This usability metric was measured by statistically analyzing and comparing the answers to the following questions in the closed-ended questionnaire for both presented conditions. This analysis was performed using single-factor ANOVA analysis for each question where the participants' answers (their value of agreement in 1-to-5 Likert scale) is the variable factor that will be used to compare the two samples (i.e., using both above-mentioned conditions). Based on the ANOVA results, we can test our hypothesis that our proposed digital in-store navigation system provides its users with more satisfying and appreciated functionalities/features while performing tasks in the context of pick-&-pack orders fulfillment and retail management processes.

- Q15: I was satisfied to use the system to understand and detect my location changes within the retail space.
- Q16: Overall, I felt comfortable while I was working with the system to accomplish the defined tasks.
- Q17: Overall, I was satisfied to use the system and I would like to use it in the future to perform similar retail-related tasks.

Open-ended questionnaire

As mentioned earlier, the open-ended questionnaire was presented to participants immediately after performing the experiment (and after filling the closed-ended one). In this questionnaire, they were asked to answer questions that help them to express their personal experience about using the system in both Condition 1 and Condition 2 (i.e., using our digital in-store navigation system in one session and using a basic non-localized digital map in another). The aim is to verbalize their thoughts and comments of this experience, and therefore, to extract more in-depth details and lengthy responses that capture the unprecedented characteristics of the UX. This collected feedback was then analyzed to support the other collected results (including ANOVA analysis and participants visual attention) of the evaluation experiment, and therefore, help us to validate our hypotheses about the system behavior and its UX.

The questionnaire consists of the following three questions:

- Q18: Do you recommend using this system to perform tasks in the context of pick-&-pack orders fulfillment and other retail management processes? If yes, please describe the pros of the system highlighting any specific features/functionalities that you like the most and you think they add to a promising positive experience? If no, please state why?
- Q19: Do you think this system allows to work and shift attention smoothly between the digital world and the physical world of the retail space leveraging the focus on tasks accomplishment, and therefore, increasing users performance? If yes, what are the system factors that relate to that? If no, please state why?

- Q20: How would you rate the system overall? and why? Please provide any further feedback about the system and any possible comments to enhance it?

6 Results

After the participants finished the defined two tasks (as described in Section 5.3.3) and completed the related open and closed-ended questionnaires for each related session in both conditions, i.e., Condition 1 using our digital in-store navigation system in one session and Condition 2 using a basic non-localized digital map in another, we started performing our analyses on the noted observations and collected feedback to present final results about the proposed system evaluation and UX validation. The results of these analyses were divided into three main parts following the proposed evaluation metrics in Section 5.4. First, the results of observing participants visual attention during tasks navigation time and related analysis are discussed in Section 6.1. Second, the results of the ANOVA analysis for the selected usability metrics are discussed in Section 6.2. Finally, Section 6.3 discusses how the final results address the defined research objectives and questions in Section 2 while analyzing other collected feedback from questionnaires answers.

6.1 Results of Tasks Duration Time and Participants Visual Attention Analysis

As we described in Section 5.4.1, we observed participants behavior during the experiment to detect any important details that can indicate UX parameters of the used system. Therefore, we consider participants visual attention during navigation as one important indicator of the provided system guidance and usability. To do so, we filtered each session for the time in which participants were working only on the defined tasks out of the session's total recorded time by excluding the time spent on "not-work" time, and the resulted filtered time was referred to as the task duration time. This task duration time was then divided into 2 main categories: navigation time and other-activities time. Analyzing the experiments of the 12 participants which in total correspond to 24 sessions (2 sessions per participant, i.e., each participant performed one session in each condition, according to the within-subject controlled experiment design), we found that the total tasks duration time of all participants sessions in both given conditions was 316,53 minutes divided into 247,17 minutes of navigation time and 69,36 minutes of other-activities time. The tasks duration time of all participants sessions in Condition 1, i.e., using our digital in-store navigation system, was 119,34 minutes varied between 7,95 to 12,35 minutes with an average of 9,95 minutes per session (standard deviation = 1,57 minutes), which is divided into 88,34 minutes of navigation time varied between 5,97 to 9,4 minutes with an average of 7,36 minutes per session (standard deviation = 1,16 minutes) and 31,00 minutes of other-activities time varied between 1,78 to 3,91 minutes with an average of 2,58 minutes per session (standard deviation = 0,58 minutes). One the other hand, the task duration time of all participants sessions in the Condition 2, i.e., using a basic non-localized digital map, was 197,19 minutes varied between 12,59 to 19,85 minutes with an average of 16,43 minutes per session (standard deviation = 1,87 minutes), which is divided into 158,83 minutes of navigation time varied between 9,93 to 16,24 minutes with an average of 13,24 minutes per session (standard deviation = 1,63 minutes) and 38,36 minutes of other-activities time varied between 2,66 to 3,63 minutes with an average of 3,20 minutes per session (standard deviation = 0,31 minutes).

These analyses are summarized in diagrams as shown in Figures 22, 23, and 24. From these figures, we can see that every single participant spent shorter time to perform the defined tasks in Condition 1 than in Condition 2, where the total tasks duration time for all participants in Condition 1 corresponds to only 38% of the total recorded tasks duration time compared to 62% in Condition 2. Moreover, every single participant spent shorter navigation time to perform the defined tasks in Condition 1 than in Condition 2, where the total tasks navigation time for all participants in Condition 1 corresponds to only 36% of the total recorded tasks navigation time

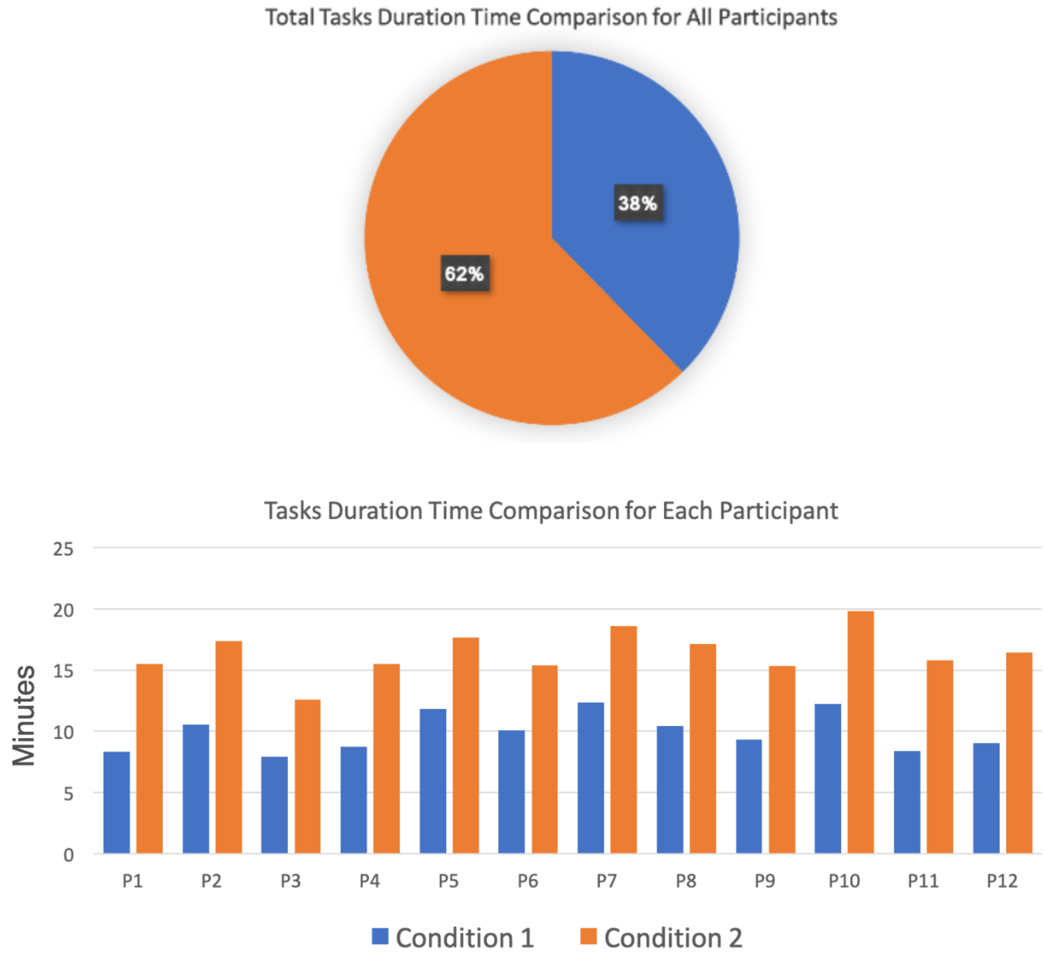
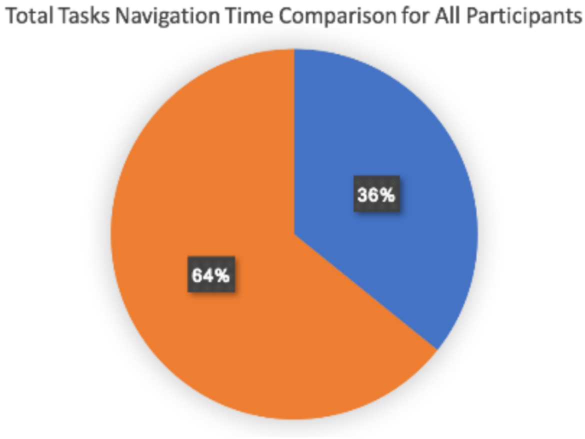


Figure 22. Tasks duration time comparison between Condition 1 (in blue) and Condition 2 (in orange). In the pie chart above, the comparison includes total time as performed by all participants together. In the clustered column chart below, the comparison is for each participant separately.

compared to 64% in Condition 2. This is an important indicator for the enhanced UX of the provided digitalized localization service in our digital in-store navigation system compared to the UX when navigating using a non-localized digital map. Furthermore, almost all participants (excluding participant number 7, i.e., P7) spent shorter other-activities time to perform the defined tasks in Condition 1 than in Condition 2, where the total tasks other-activities time for all participants in Condition 1 corresponds to 45% of the total recorded tasks other-activities time compared to 55% in Condition 2. This also can be considered as a reasonable indication for the enhanced UX of the provided functionalities (e.g., inserting, searching, and updating an item digitally) and embedded features (e.g., flexible choice between barcode scanning and EAN typing, simplified number and order of steps to perform each single functionality, other design features, etc.) of our proposed system compared to the UX when using a non-unified interface for both monitoring navigation and performing other retail-related activities in the retail space while fulfilling pick-&-pack orders.

Afterward, since our evaluation study targeted UX validation of the in-store navigation feature as the main aspect of our digitalized localization service and implemented system, we analyzed the navigation time separately focusing on participants visual attention. To do so, navigation time for each participant/session in both conditions was categorized/coded using the visual categories/codes summarized in Table 2.6 following the explained procedure in Section 5.4.1. The results of this categorization showed a comparison of how much time participants spent relatively in each visual attention state (i.e., mobile view, surrounding view, alternate view), either each participant separately



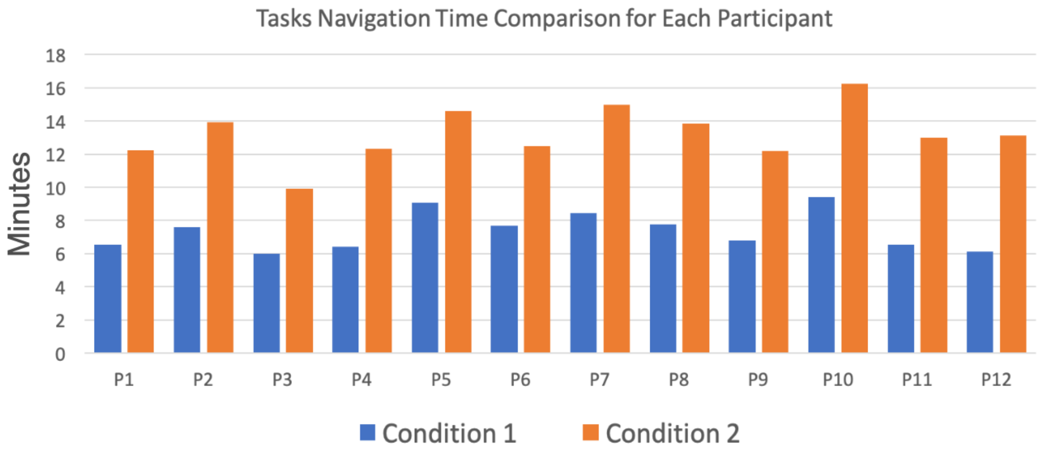


Figure 23. Tasks navigation time comparison between Condition 1 (in blue) and Condition 2 (in orange). In the pie chart above, the comparison includes total time as performed by all participants together. In the clustered column chart below, the comparison is for each participant separately.

or altogether, in both conditions as summarized in Figure 25.

According to the analysis, all participants in Condition 1 spent 88,34 minutes of tasks navigation time, which is categorized into 15,01 minutes (corresponding to 17% of the total navigation time) in the mobile-view state varied between 0,95 to 1,43 minutes with an average of 1,25 minutes per session (standard deviation = 0,15 minutes) and 13,06 minutes (corresponding to 15% of the total navigation time) in the surrounding-view state varied between 0,73 to 1,39 minutes with an average of 1,09 minutes per session (standard deviation = 0,19 minutes) and 60,27 minutes (corresponding to 68% of the total navigation time) in the alternate-view state varied between 3,77 to 6,88 minutes with an average of 5,02 minutes per session (standard deviation = 1,00 minutes). On the other hand, all participants in Condition 2 spent 158,83 minutes of tasks navigation time, which is categorized into 49,31 minutes (corresponding to 31% of the total navigation time) in the mobile-view state varied between 3,25 to 5,23 minutes with an average of 4,11 minutes per session (standard deviation = 0,60 minutes) and 39,77 minutes (corresponding to 25% of the total navigation time) in the surrounding-view state varied between 2,35 to 3,88 minutes with an average of 3,31 minutes per session (standard deviation = 0,51 minutes) and 69,75 minutes (corresponding to 44% of the total navigation time) in the alternate-view state varied between 4,15 to 7,13 minutes with an average of 5,81 minutes per session (standard deviation = 0,75 minutes).

Based on these collected data and analysis, participants spent 68% of their tasks navigation time in the alternate-view state when using our digital in-store navigation system (i.e., Condition 1), while they only spent 44% in the same state when using a non-localized digital map. This significant

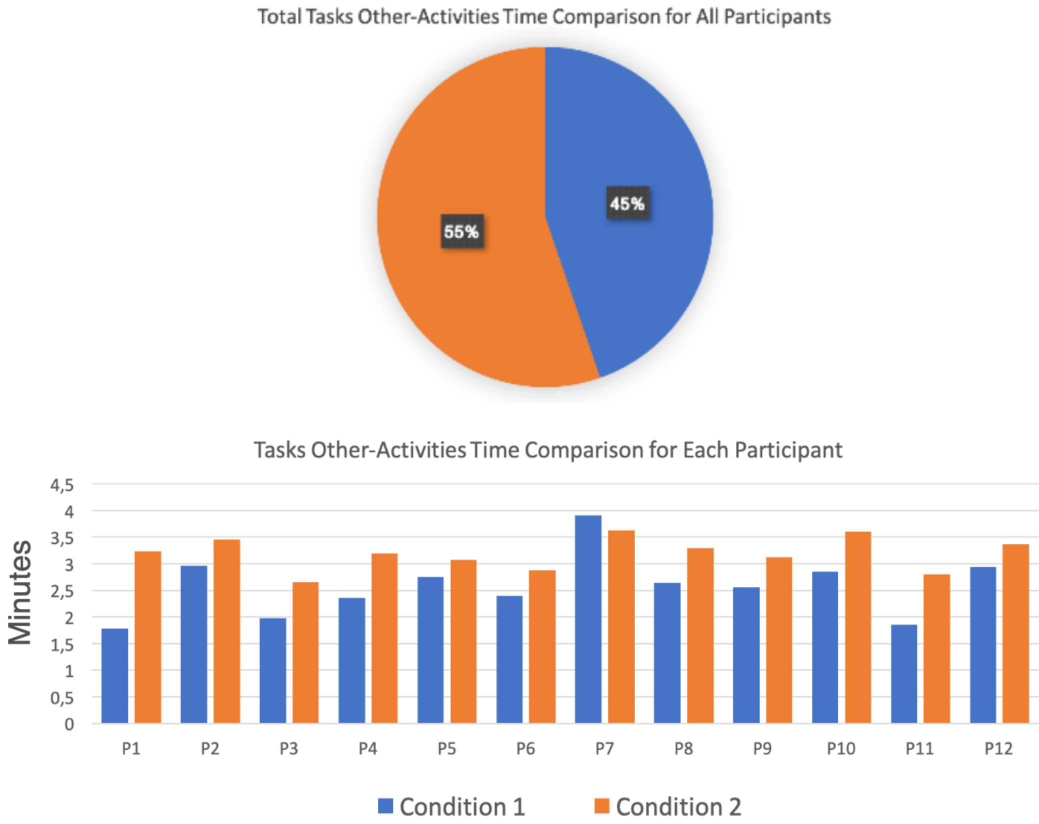


Figure 24. Tasks other-activities time comparison between Condition 1 (in blue) and Condition 2 (in orange). In the pie chart above, the comparison includes total time as performed by all participants together. In the clustered column chart below, the comparison is for each participant separately.

difference can be considered as a good indication that our digital in-store navigation system provided participants with more flawless experience between digital world (mainly through communicating with the mobile screen) and the physical world (while interacting with the surrounding environment and physical items in the retail floor) compared to that experience provided by a non-localized digital map. In other words, when using a non-localized digital map solution, participants were focusing too much on the artifacts, both digitally and physically, instead of working simultaneously and smoothly with both to focus on accomplishing the defined tasks, which was better facilitated and offered when using our proposed system. As a result, we conclude that our proposed system enhanced the UX of a navigating retail employee while fulfilling the pick-&-pack orders and other retail management processes.

6.2 Results of the Closed-Ended Questionnaire and Related ANOVA Analysis of Usability Measures

Considering the discussed UX metrics in Section 6.1, which are mainly based on analyzing the total tasks duration time of all participants and interrupt their visual attention during navigation to describe and compare the provided UX in both conditions, we present in this section the analysis results of the other UX metrics as perceived by the evaluation study participants. This analysis followed the procedure discussed in Section 5.4.2 by providing a set of closed-ended questions aiming to measure the defined UX metrics including learnability, perceived ease of use, perceived usefulness, trust, and satisfaction. Such a closed-ended questionnaire would allow a fair assessment of the concrete system features and their design, based on affective, cognitive, behavioral, sensory, and

Figure 25. Comparing tasks navigation time of each visual attention state between Condition 1 (to the left) and Condition 2 (to the right) for all participants together (in the pie chart above) and for each participant separately (in the stacked column chart below).

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Q17
P1	5	5	4	3	3	5	5	5	5	5	5	5	4	4	5	5	5
P2	4	4	4	2	3	5	5	4	4	4	4	5	4	4	5	5	4
P3	5	5	5	4	4	5	5	5	5	5	5	5	5	5	5	5	5
P4	4	4	4	2	2	4	4	4	4	4	4	4	4	4	5	5	4
P5	4	4	4	2	2	5	5	4	4	4	4	4	4	4	4	4	4
P6	5	5	4	3	3	5	5	5	4	5	5	5	4	5	5	5	4
P7	4	4	5	2	2	4	4	4	4	4	4	5	4	4	4	4	4
P8	4	5	4	3	3	5	5	5	4	5	5	5	4	4	5	5	5
P9	4	5	4	3	3	5	5	5	5	5	5	5	4	4	5	5	5
P10	3	3	3	2	2	3	4	4	3	3	4	4	4	4	4	4	4
P11	5	5	5	3	3	5	5	5	4	5	5	5	4	5	5	5	5
P12	5	5	5	3	3	5	5	5	5	5	5	5	4	4	5	5	5
Avg	4,33	4,50	4,25	2,67	2,75	4,67	4,75	4,58	4,25	4,50	4,58	4,75	4,08	4,25	4,75	4,75	4,50

Table 2.7. Participants answers to the closed-ended questions for Condition 1.

social elements. Besides, the questionnaire would explore aspects relevant to assessing the location awareness that is considered an important characteristic of this kind of applications designed for practical usage in a multi-touch-point smart retail space. The participants answers to the closed-ended questionnaire are shown in Table 2.7 for Condition 1 experiment sessions and Table 2.8 for Condition 2 experiment sessions. These questionnaire results were categorized based on the defined UX metrics and were analyzed accordingly using single-factor ANOVA analysis to compare participants answers of each question for both Condition 1 and Condition 2 as described in the following parts.

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Q17
P1	3	2	2	4	4	2	3	3	1	1	2	1	4	3	2	2	2
P2	1	1	1	4	4	2	2	2	1	1	1	1	3	3	1	2	2
P3	3	2	2	5	5	3	3	2	2	2	2	2	4	4	1	2	3
P4	1	1	1	4	4	1	3	3	1	1	1	1	3	3	2	2	2
P5	1	2	1	4	4	1	2	3	1	1	1	1	4	4	2	2	2
P6	2	1	1	5	5	2	3	3	2	2	1	2	4	3	3	3	3
P7	1	2	2	3	4	3	3	3	2	2	2	2	4	4	3	3	3
P8	2	2	1	4	5	1	3	1	1	1	1	1	3	3	2	2	2
P9	2	1	1	4	5	1	2	2	1	1	1	1	3	3	2	2	2
P10	1	1	1	3	4	1	2	1	1	2	1	1	3	2	1	2	2
P11	2	2	2	4	4	2	3	2	2	2	2	2	4	3	2	2	2
P12	2	2	2	4	5	3	3	2	1	1	2	1	3	3	2	2	2
Avg	1,75	1,58	1,42	4,00	4,42	1,83	2,67	2,25	1,33	1,42	1,42	1,33	3,50	3,17	1,92	2,17	2,25

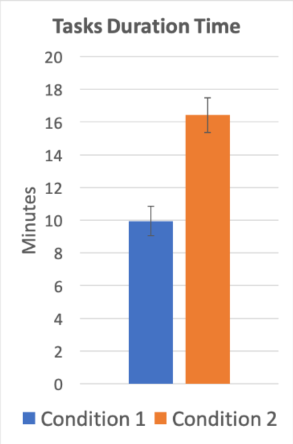
Table 2.8. Participants answers to the closed-ended questions for Condition 2.

Task Duration Time

Previously in Section 6.1, we analyzed the tasks duration time, either as a whole or for navigation and other-activities time apart, of all participants (altogether and each one separately) in both conditions with the main focus on observing participants behavior and visual attention during navigation time to analyze UX patterns and measures related to the main feature of our proposed system, i.e., in-store navigation via a digitalized localization service. In this section, we want to validate the significance of the enhanced UX of our proposed system by testing our hypothesis statistically that our proposed digital in-store navigation system requires shorter time to perform tasks than a non-localized digital map (as a basic reference for a navigation solution) in the context of pick-&-pack orders fulfillment and retail management processes. To do so, we run single-factor ANOVA analysis where the tasks duration time is the variable factor that will be used to compare the two samples (i.e., between Condition 1 and Condition 2). The results of our ANOVA analysis are shown in Figure 26. On the left of the figure, we can see the average tasks duration time for all participants in both conditions and the related 95 percent confidence interval. On the right of the figure, we can see the details of the ANOVA analysis where it shows (in blue) that F > F crit (84,69»4,3) and (in green) P-value < selected alpha (0,000000005«0.05). These results indicate with a very high probability that differences of required tasks duration time between Condition 1 and Condition 2 are significant and not due to chance. Therefore, we can accept our hypothesis that Condition 1 requires shorter tasks duration time than Condition 2.

Location Awareness

Following the procedure discussed in Section 5.4.2, the analysis started by providing a set of closed-ended questions aiming to measure participants location awareness as a defined UX metric. The given questions to this metric are Q1, Q2, and Q3, whereas participants corresponding answers to these question in Condition 1 and Condition 2 are summarized in Table 2.7 and Table 2.8 respectively. In this section, we want to use the collected answers to validate the significance of the enhanced UX of our proposed system by testing our hypothesis statistically that our proposed digital in-store navigation system provides better location awareness than a non-localized digital map (as a basic reference for a navigation solution) while performing tasks in the context of pick-&-pack orders fulfillment and retail management processes. To do so, we run single-factor ANOVA analysis for each given question where the participants answers (their value of agreement in 1-to-5 Likert scale) is the variable factor that will be used to compare the two samples (i.e., between Condition 1 and Condition 2). The results of our ANOVA analysis are shown in Figure 27. On the left of the figure, we can see the average rankings for all participants in both conditions and the related 95 percent confidence interval. On the right of the figure, we can see the details of the ANOVA analysis where it shows for all given questions that (in blue) F > F crit (80,69»4,3 for Q1, 141,84»4,3



Anova: Single Factor

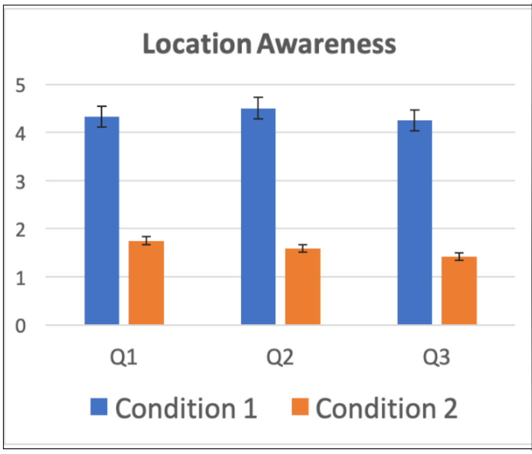
SUMMARY

Groups	Count	Sum	Average	Variance
Condition 1	12	119,34	9,945	2,450663636
Condition 2	12	197,19	16,4325	3,512856818

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	252,5259375	1	252,5259375	84,69022264	0,000000005	4,300949502
Within Groups	65,598725	22	2,981760227			
Total	318,1246625	23				

Figure 26. Single-factor ANOVA analysis results comparing the tasks duration time as performed by all participants in Condition 1 and Condition 2. Comparing the calculated F values (marked in blue) shows that F > F crit. Further, P-value (marked in green) < selected alpha (0.05). Therefore, we can accept our hypothesis that Condition 1 requires shorter tasks duration time than Condition 2.



ANOVA **Q1**

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	40,0416667	1	40,0416667	80,6946565	0,000000008	4,3009495
Within Groups	10,9166667	22	0,49621212			

ANOVA **Q2**

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	51,0416667	1	51,0416667	141,842105	4,59523E-11	4,3009495
Within Groups	7,91666667	22	0,35984848			

ANOVA **Q3**

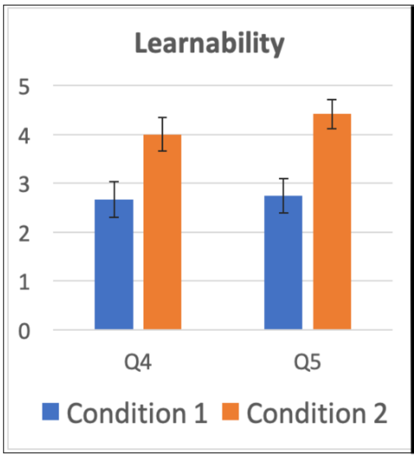
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	48,1666667	1	48,1666667	147,860465	3,08244E-11	4,3009495
Within Groups	7,16666667	22	0,32575758			

Figure 27. Single-factor ANOVA analysis results comparing participants answers in Condition 1 and Condition 2 for the closed-ended questions related to location awareness UX metric. Comparing the calculated F values (marked in blue) shows that F > F crit for all questions. Further, P-value (marked in green) < selected alpha (0.05). Therefore, we can accept our hypothesis that Condition 1 provides better location awareness than Condition 2.

for Q2, and 147,86»4,3 for Q3) and (in green) P-value < selected alpha (0,000000008«0.05 for Q1, 4,6E-11«0.05 for Q2, and 3,1E-11«0.05 for Q3). These results indicate with a very high probability that differences of provided location awareness between Condition 1 and Condition 2 are significant and not due to chance. Therefore, we can accept our hypothesis that Condition 1 provides better location awareness than Condition 2.

Learnability

Following the procedure discussed in Section 5.4.2, the analysis started by providing a set of closed-ended questions aiming to measure the learnability of the system (i.e., needed cognitive effort by participants to grasp, intuitively understand, and possibly learn the system's design and provided functionalities/features) as a defined UX metric. The given questions to this metric are Q4 and Q5,



ANOVA Q4						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	10,6666667	1	10,6666667	27,0769231	0,00003	4,3009495
Within Groups	8,66666667	22	0,39393939			

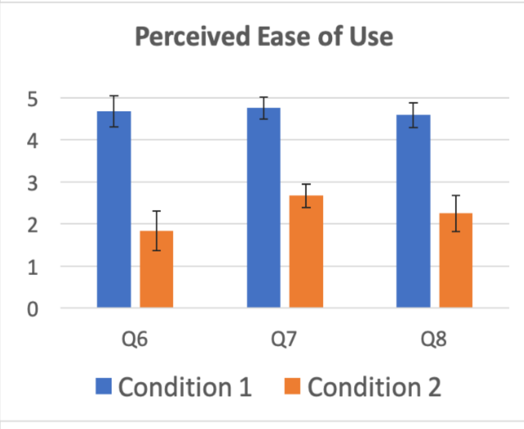
ANOVA Q5						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	16,6666667	1	16,6666667	51,1627907	0,0000004	4,3009495
Within Groups	7,16666667	22	0,32575758			

Figure 28. Single-factor ANOVA analysis results comparing participants answers in Condition 1 and Condition 2 for the closed-ended questions related to learnability UX metric. Comparing the calculated F values (marked in blue) shows that F > F crit for all questions. Further, P-value (marked in green) < selected alpha (0.05). Therefore, we can accept our hypothesis that Condition 1 requires more learning effort than Condition 2.

whereas participants corresponding answers to these question in Condition 1 and Condition 2 are summarized in Table 2.7 and Table 2.8 respectively. In this section, we want to use the collected answers to validate the significance of the enhanced UX of our proposed system by testing our hypothesis statistically that our proposed digital in-store navigation system requires more learning effort than a non-localized digital map (as a basic reference for a navigation solution) since it provides more digitally embedded functionalities/features while performing tasks in the context of pick-&-pack orders fulfillment and retail management processes. To do so, we run single-factor ANOVA analysis for each given question where the participants answers (their value of agreement in 1-to-5 Likert scale) is the variable factor that will be used to compare the two samples (i.e., between Condition 1 and Condition 2). The results of our ANOVA analysis are shown in Figure 28. On the left of the figure, we can see the average rankings for all participants in both conditions and the related 95 percent confidence interval. On the right of the figure, we can see the details of the ANOVA analysis where it shows for all given questions that (in blue) F > F crit (27,08»4,3 for Q4 and 51,16»4,3 for Q5) and (in green) P-value < selected alpha (0,00003«0.05 for Q4 and 0,0000004«0.05 for Q5). These results indicate with a high probability that differences of required learning effort between Condition 1 and Condition 2 are significant and not due to chance. Therefore, we can accept our hypothesis that Condition 1 requires more learning effort than Condition 2. It should be noted that this result is not necessarily a negative point since our digital in-store navigation system provides more digitally embedded functionalities/features to accomplish tasks efficiently, which other basic non-localized digital maps don't provide, and therefore, additional learning effort will not be even needed in that case.

Perceived Ease of Use

Following the procedure discussed in Section 5.4.2, the analysis started by providing a set of closed-ended questions aiming to measure the system's ease of use (i.e., how easy to use the system as perceived by participants) as a defined UX metric. The given questions to this metric are Q6, Q7, and Q8, whereas participants corresponding answers to these question in Condition 1 and Condition 2 are summarized in Table 2.7 and Table 2.8 respectively. In this section, we want to use the collected answers to validate the significance of the enhanced UX of our proposed system by testing our hypothesis statistically that our proposed digital in-store navigation system is easier to use than a non-localized digital map (as a basic reference for a navigation solution) while performing



ANOVA Q6

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	48,1666667	1	48,1666667	85,9189189	0,000000005	4,3009495
Within Groups	12,3333333	22	0,56060606			

ANOVA Q7

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	26,0416667	1	26,0416667	116,525424	2,94997E-10	4,3009495
Within Groups	4,91666667	22	0,22348485			

ANOVA Q8

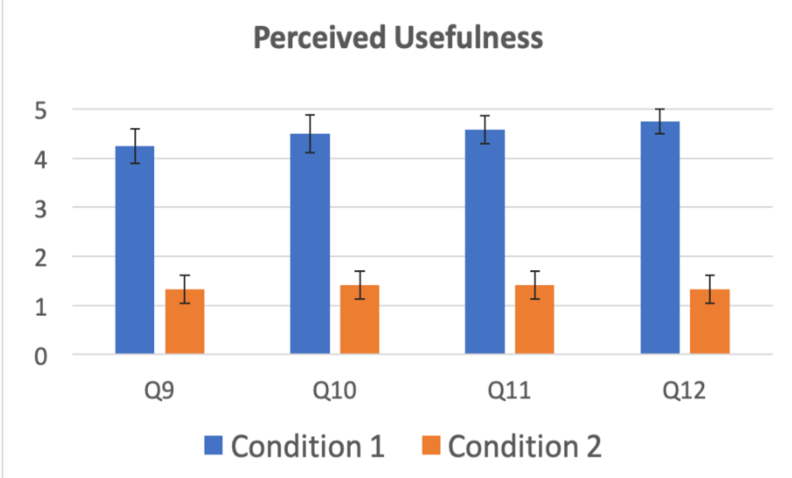
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	32,6666667	1	32,6666667	78,4	0,000000011	4,3009495
Within Groups	9,16666667	22	0,41666667			

Figure 29. Single-factor ANOVA analysis results comparing participants answers in Condition 1 and Condition 2 for the closed-ended questions related to perceived ease of use UX metric. Comparing the calculated F values (marked in blue) shows that F > F crit for all questions. Further, P-value (marked in green) < selected alpha (0.05). Therefore, we can accept our hypothesis that Condition 1 is easier to use than Condition 2.

tasks in the context of pick-&-pack orders fulfillment and retail management processes. To do so, we run single-factor ANOVA analysis for each given question where the participants answers (their value of agreement in 1-to-5 Likert scale) is the variable factor that will be used to compare the two samples (i.e., between Condition 1 and Condition 2). The results of our ANOVA analysis are shown in Figure 29. On the left of the figure, we can see the average rankings for all participants in both conditions and the related 95 percent confidence interval. On the right of the figure, we can see the details of the ANOVA analysis where it shows for all given questions that (in blue) F > F crit (85,92»4,3 for Q6, 116,53»4,3 for Q7, and 78,4»4,3 for Q8) and (in green) P-value < selected alpha (0,000000005«0.05 for Q6, 2,9E-10«0.05 for Q7, and 0,000000011«0.05 for Q8). These results indicate with a high probability that differences of system's ease of use between Condition 1 and Condition 2 are significant and not due to chance. Therefore, we can accept our hypothesis that Condition 1 is easier to use than Condition 2.

Perceived Usefulness

Following the procedure discussed in Section 5.4.2, the analysis started by providing a set of closed-ended questions aiming to measure the system's usefulness (i.e., how useful the system is as perceived by participants) as a defined UX metric. The given questions to this metric are Q9, Q10, Q11, and Q12, whereas participants corresponding answers to these question in Condition 1 and Condition 2 are summarized in Table 2.7 and Table 2.8 respectively. In this section, we want to use the collected answers to validate the significance of the enhanced UX of our proposed system by testing our hypothesis statistically that our proposed digital in-store navigation system provides more useful functionalities/features than a non-localized digital map (as a basic reference for a navigation solution) while performing tasks in the context of pick-&-pack orders fulfillment and retail management processes. To do so, we run single-factor ANOVA analysis for each given question where the participants answers (their value of agreement in 1-to-5 Likert scale) is the variable factor that will be used to compare the two samples (i.e., between Condition 1 and Condition 2). The results of our ANOVA analysis are shown in Figure 30. On the left of the figure, we can see the average rankings for all participants in both conditions and the related 95 percent confidence interval. On the right of the figure, we can see the details of the ANOVA analysis where it shows for all given questions that (in blue) F > F crit (162,35»4,3 for Q9, 158,52»4,3 for Q10, 226,91»4,3 for Q11, and 313,41»4,3 for Q12) and (in green) P-value < selected alpha (1,25E-11«0.05 for Q9,



ANOVA **Q9**						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	51,0416667	1	51,0416667	162,349398	1,24612E-11	4,3009495
Within Groups	6,91666667	22	0,31439394			

ANOVA **Q10**						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	57,0416667	1	57,0416667	158,515789	1,57224E-11	4,3009495
Within Groups	7,91666667	22	0,35984848			

ANOVA **Q11**						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	60,1666667	1	60,1666667	226,914286	4,51078E-13	4,3009495
Within Groups	5,83333333	22	0,26515152			

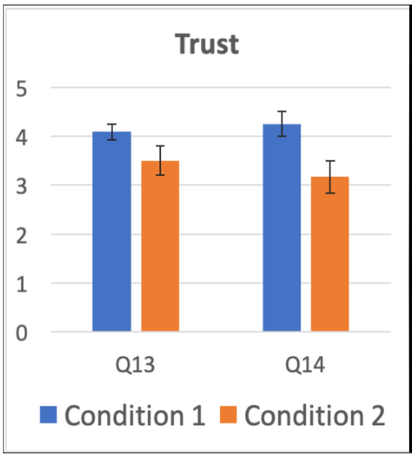
ANOVA **Q12**						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	70,0416667	1	70,0416667	313,40678	1,67735E-14	4,3009495
Within Groups	4,91666667	22	0,22348485			

Figure 30. Single-factor ANOVA analysis results comparing participants answers in Condition 1 and Condition 2 for the closed-ended questions related to perceived usefulness UX metric. Comparing the calculated F values (marked in blue) shows that F > F crit for all questions. Further, P-value (marked in green) < selected alpha (0.05). Therefore, we can accept our hypothesis that Condition 1 provides more useful functionalities/features than Condition 2.

1,57E-11«0.05 for Q10, 4,51E-13«0.05 for Q11, and 1,68E-14«0.05 for Q12). These results indicate with a high probability that differences of system's usefulness between Condition 1 and Condition 2 are significant and not due to chance. Therefore, we can accept our hypothesis that Condition 1 provides more useful functionalities/features to perform the related retail tasks than Condition 2.

Trust

Following the procedure discussed in Section 5.4.2, the analysis started by providing a set of closed-ended questions aiming to measure participants trust in the system (i.e., how trustworthy and reliable the system's features, functionalities, and provided information are) as a defined UX metric. The given questions to this metric are Q13 and Q14, whereas participants corresponding answers to these question in Condition 1 and Condition 2 are summarized in Table 2.7 and Table 2.8 respectively. In this section, we want to use the collected answers to validate the significance of the enhanced UX of our proposed system by testing our hypothesis statistically that our proposed digital in-store navigation system provides its users with more trustworthy and reliable functionalities, features, and



ANOVA Q13						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2,04166667	1	2,04166667	11,4680851	0,002655748	4,3009495
Within Groups	3,91666667	22	0,1780303			

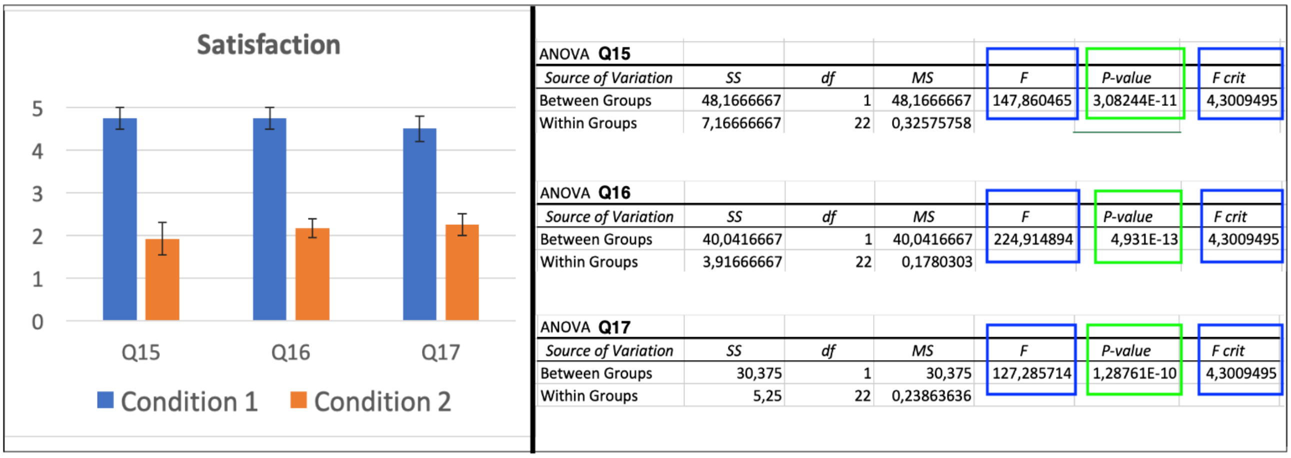
ANOVA Q14						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	7,04166667	1	7,04166667	26,1830986	0,00004	4,3009495
Within Groups	5,91666667	22	0,26893939			

Figure 31. Single-factor ANOVA analysis results comparing participants answers in Condition 1 and Condition 2 for the closed-ended questions related to perceived usefulness UX metric. Comparing the calculated F values (marked in blue) shows that F > F crit for all questions. Further, P-value (marked in green) < selected alpha (0.05). Therefore, we can accept our hypothesis that Condition 1 provides more useful functionalities/features to perform the related retail tasks than Condition 2.

information (e.g., localization information, items information, etc.) than a non-localized digital map (as a basic reference for a navigation solution) while performing tasks in the context of pick-&-pack orders fulfillment and retail management processes. To do so, we run single-factor ANOVA analysis for each given question where the participants answers (their value of agreement in 1-to-5 Likert scale) is the variable factor that will be used to compare the two samples (i.e., between Condition 1 and Condition 2). The results of our ANOVA analysis are shown in Figure 31. On the left of the figure, we can see the average rankings for all participants in both conditions and the related 95 percent confidence interval. On the right of the figure, we can see the details of the ANOVA analysis where it shows for all given questions that (in blue) F > F crit (11,47>4,3 for Q13 and 26,18»4,3 for Q14) and (in green) P-value < selected alpha (0,0027«0.05 for Q13 and 0,00004«0.05 for Q14). These results indicate with a high probability that differences of participants trust in the system between Condition 1 and Condition 2 are significant and not due to chance. Therefore, we can accept our hypothesis that Condition 1 provides more trustworthy and reliable features, functionalities, and information than Condition 2.

Satisfaction

Following the procedure discussed in Section 5.4.2, the analysis started by providing a set of closed-ended questions aiming to measure participants satisfaction of using the system (i.e., how satisfactory and appreciated to use the provided system's functionalities and features) as a defined UX metric. The given questions to this metric are Q15, Q16, and Q17, whereas participants corresponding answers to these question in Condition 1 and Condition 2 are summarized in Table 2.7 and Table 2.8 respectively. In this section, we want to use the collected answers to validate the significance of the enhanced UX of our proposed system by testing our hypothesis statistically that our proposed digital in-store navigation system provides more satisfactory and appreciated features and functionalities than a non-localized digital map (as a basic reference for a navigation solution) while performing tasks in the context of pick-&-pack orders fulfillment and retail management processes. To do so, we run single-factor ANOVA analysis for each given question where the participants answers (their value of agreement in 1-to-5 Likert scale) is the variable factor that will be used to compare the two samples (i.e., between Condition 1 and Condition 2). The results of our ANOVA analysis are shown in Figure 32. On the left of the figure, we can see the average rankings for all participants in both



ANOVA **Q15**						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	48,1666667	1	48,1666667	147,860465	3,08244E-11	4,3009495
Within Groups	7,16666667	22	0,32575758			

ANOVA **Q16**						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	40,0416667	1	40,0416667	224,914894	4,931E-13	4,3009495
Within Groups	3,91666667	22	0,1780303			

ANOVA **Q17**						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	30,375	1	30,375	127,285714	1,28761E-10	4,3009495
Within Groups	5,25	22	0,23863636			

Figure 32. Single-factor ANOVA analysis results comparing participants answers in Condition 1 and Condition 2 for the closed-ended questions related to users satisfaction UX metric. Comparing the calculated F values (marked in blue) shows that F > F crit for all questions. Further, P-value (marked in green) < selected alpha (0.05). Therefore, we can accept our hypothesis that Condition 1 provides more satisfactory and appreciated features and functionalities than Condition 2.

conditions and the related 95 percent confidence interval. On the right of the figure, we can see the details of the ANOVA analysis where it shows for all given questions that (in blue) F > F crit (147,86»4,3 for Q15, 224,92»4,3 for Q16 127,29»4,3 for Q17) and (in green) P-value < selected alpha (3,08E-11«0.05 for Q15, 4,93E-13«0.05 for Q16, and 1,29E-10«0.05 for Q17). These results indicate with a high probability that differences of participants satisfaction of using the system between Condition 1 and Condition 2 are significant and not due to chance. Therefore, we can accept our hypothesis that Condition 1 provides more satisfactory and appreciated features and functionalities than Condition 2.

6.3 Addressing Research Questions and Other Collected Feedback

Results of the Open-Ended Questionnaire

Before addressing the defined research questions in Section2, we need to analyze other collected feedback mainly through the open-ended questionnaire. Most of the participants found that our digital in-store navigation system is easy to use. P3 commented that the interaction with the system is good and flexible, which makes the system easy to use and useful. P12 elaborated that using simple yet meaningful icon symbols to categorize functionalities in the mobile application interface increases the memorable usability dimension. Moreover, most of the participants appreciated that the system allows choosing between different options to search, insert, or update items when performing retail management processes. Further, they also found that the provided platform offers a practical solution to navigate the space and route users to their destination goals promoting location awareness. For example, P1 found the platform pretty good for understanding the different parts of the space layout and mentioned that it helps to find items and destination locations in a shorter time. Additionally, many participants found it convenient to interact with both physical and digital touchpoints in the space simultaneously. In their opinion, they could perform the tasks smoothly and achieve excellent results in terms of time and effort, which makes them feel satisfied at the end. However, they also suggested that the system could provide extra interaction modalities to facilitate work like providing vocal interaction and voice commands corresponding to the displayed visual content that can guide users step by step during navigation until they reach their destination location, and therefore, it could be very helpful to reduce needed visual attention and stay focused on the tasks rather than the artifacts (both physical and digital).

In comparison, participants in some cases declared that they had difficulties at the beginning to cope with the system, as expected by our hypothesis regarding system learnability. This could be obvious when a system provides more functionalities and features which should be designed and implemented carefully to avoid complicated architecture, confusing interface, and frustrating experience. P10 had a problem to understand the system in the beginning, though, others expressed that they could easily cope with it after a short time, which indicates the potential for the system learnability. Besides, other participants, like P5, found that the interaction is not essential when users work mainly in the physical environment (e.g., when placing a new item physically on the destination shelf). In their opinion, interaction is important only when users need navigation guidance, which is basically the focus of our system and the implemented digital localization service. They added that interaction in such case is necessary to avoid conflicts in the results. For example, if two users want to insert the same new item digitally into the system at the same time, then they need some form of synchronization supported by the system between them to avoid chaos.

On the other hand, many participants commented about the general use of the in-store navigation system and proposed other innovative ideas and suggestions to enhance it. Some participants suggested adding more functionalities to increase the usability of the system. For instance, adding notifications as new functionality, which could show notifications on the interface to all other active users when a user inserts or updates an item in the retail space. Similarly, other participants suggested instant feedback mode, where the information about the committed actions is made visible immediately rather than having to check them manually. This can be realized by using a color code to highlight newly added and recently updated icons on the map (e.g., highlighting those icons with green color for the newly inserted and yellow color for the recently updated). Some participants suggest applying this system to other industries and various fields. For example, P7 suggested that the system can be extended to other scenarios and uses cases in different kind of spaces like hospitals, museums, universities, etc. Other participants added that collaboration environments with multi-users nature can also make use of such an application. P9 explained that the locations of the other navigating users can be shown simultaneously on the map, and therefore, collaboration opportunities between users can facilitate the work. For instance, if one user is assigned a task in the distant part from her current location within the retail layout, she can reassign that task to another user who is already located there. In this case, the system helps to reassign tasks based on current users locations within the space layout while promoting users to collaborate to accomplish tasks and encourage them to build stronger collaborative relationships, which in total increases the overall performance and leverages users satisfaction. Overall, participants feedback and comments emphasized that the system is easy to use, user-friendly, satisfying, accessible and efficient. This can be also concluded from the participants answers for the closed-ended questions as previously shown in table 2.7.

Analyzing Overall Collected Results and Feedback in Addressing Research Questions

Finally, after conducting the evaluation user study and collecting answers of closed-ended and open-ended questionnaires, we can use all these results and gathered feedback to address and answer our defined research objectives and questions mentioned in Section2. Regarding the first question, i.e., RQ1, we found that the immersiveness of smart retail spaces is gradually increasing in recent years as discussed in the related work. This can be seen in the advances of provided IoT systems and related devices and sensors. In our case of realizing digital localization service, we found that there are different possible IoT technologies and sensors that can be applied to implement this service according to the defined degree of accuracy and responsiveness. This can be directly related to the selected methodology (e.g., beacons-based trilateration, proximity detection, presence detection only, etc.) and the particular technology preference (e.g., choosing BLE over UWB beacons as they cost less and easily communicate with all kind of mobile devices with embedded Bluetooth module while providing accepted accuracy for our case study and scenario). Such technologies can be customized flexibly to apply required algorithmic intelligence while complying with privacy and personal data protection restrictions like GDPR. However, to ensure a sustainable immersiveness of smart retail spaces, we should keep following the advent technologies and technology trends and keep an up-to-date technological design and solution.

Regarding the second question, i.e., RQ2, we found that embodied interaction techniques are considered one of the main factors to provide a promising UX and related digital service innovation. In our case study, for example, touch-based interaction with the system provides a good solution to facilitate tasks completion. However, participants indicated clearly that providing vocal interaction and voice commands in parallel to the displayed visual content can guide users step by step during navigation until they reach their destination location, and therefore, it could be very helpful to reduce needed visual attention and stay focus on the tasks rather than the artifacts (both physical and digital). Selecting all possible and suitable interactions to provide state-of-art multimodality in implementing digital services will inevitably lead to the required innovation.

Regarding the third question, i.e., RQ3, we found that wise and considerable planning to exploit UX classes in the full realization (i.e., design, implementation, and evaluation) of a digital service has a significant effect to leverage UX and derive the required service innovation. In our case study, considering UX characteristics and measures like system's efficiency, meaningfulness, perceived usefulness, promoted location awareness, trustworthy and reliable information, satisfactory features and functionalities, etc., ensured a well-exploited UX of the realized digital localization service. This was also considered by following user acceptance factors to derive the optimal usage of the system and related digital services integrated into the smart space, which is indicated by the fourth question, i.e., RQ4. This was also reflected in evaluation study results where participant clearly expressed their perceived ease of use and usefulness of the provided system, while considering other factors than the technical ones related to cultural differences (as the participants come from a very diverse cultures) and individual differences (considering participants with different ages, fields of knowledge, and expertise with digital systems).

Finally, other questions, i.e., RQ5 and RQ6, were not completely addressed. For example, enhancing UX by extending the application of the system into other environments like living environment (e.g., handling tasks from home) and service environments (e.g., promoting social-media-based marketing of the available items) was not mainly targeted due to the nature of our defined use case of handling pick-&-pack orders for retail employees, which intersects less with these environments domains and deals more with retail-specific aspects like navigation. However, when a retail customer version of the application is realized in the future, these environments can be directly considered. Furthermore, related employed technological aspects of participants health, social relations, and the environment were not fully exploited. This was partially argued by the collected feedback of some participants that the proposed in-store navigation system can provide a multi-user solution in which participants collaborate to accomplish tasks, which has a direct positive impact on the social relations building, and therefore, leveraging UX and the required provided service innovation.

Chapter 3

Clinical Guidelines as a Service: Supporting an Efficient Patient-Centered Operation of Digital Clinical Guidelines in Smart Healthcare Spaces

1 Introduction

Healthcare is conventionally regarded as the act of taking preventative or necessary medical procedures to improve a person's well-being [195]. Such procedures are typically offered through a healthcare system made up of hospitals and professionals (such as general practitioners, nurses, doctors, etc.) working in a multidisciplinary environment with complex decision making responsibilities. The notion of smart healthcare spaces refers to the adoption of ubiquitous computing devices together with IoT clinical devices and objects embedded into such spaces, which can communicate and share data to facilitate the complexity of the clinical tasks and activities. An important example of these ubiquitous devices is the smart mobile devices and their integrated technologies that show promising potential in various fields including healthcare (as we already discussed their promising role in the retail industry in Chapter 2). Therefore, the second case study of this thesis is directed towards the smart healthcare spaces to facilitate the work of doctors and other medical staff in their clinical tasks and activities. In particular, we aim to realize a user-centered approach for the digitalization of a specific class of clinical services, called clinical guidelines, which are deployed in smart healthcare spaces while leveraging clinical mobile technologies.

With the advent of advanced health information technology (HIT) and electronic health records (EHR) in the mid-2000s [327], hospitals started to manage and share patient information electronically rather than through paper records. This has led to a growing usage of handwriting capable mobile technologies and devices able to sync up with EHR systems, thus allowing doctors to access patient records from remote locations and support them in the delivery of care procedures. Consequently, it is not unusual that a doctor visits a patient interacting with several mobile devices at the same time.

Notwithstanding the benefits of EHR systems and mobile technologies towards improving the delivery of care procedures [87, 97, 73, 193], there are also indications that their use may have a negative impact on patient-centeredness [299]. This often results in higher physical and cognitive efforts of doctors while visiting patients, making them more inclined to make medical mistakes [277] and lose the rapport with their patients [68, 221]. However, as pointed out in [192], multi-tasking and information transfers through EHR systems have become necessary aspects of healthcare environments, which can not be avoided entirely.

While the realization of a technological solution that supports doctors in the enactment of care procedures through mobile devices requiring a limited physical/cognitive effort for their usage, and that ensures the continuity of information flow through EHR systems, would be desirable, to date, most of the existing solutions focus exclusively on one aspect of the foregoing requirements or a partial combination of them [273].

On the one hand, the Human–Computer Interaction (HCI) community has investigated how the use of *multimodal interfaces* has the potential to reduce the cognitive efforts on users that manage complex activities such as the clinical ones. For example, in [249], the authors state that "*multimodal interface users spontaneously respond to dynamic changes in their own cognitive load by shifting to multimodal communication as load increases with task difficulty and communicative complexity*". Furthermore, recent research by Pieh et al. [257] has shown that multimodal approaches to healthcare deliver the most effective results, compared to a single modality on its own.

On the other hand, the Business Process Management (BPM) community has studied how to organize clinical activities in well-structured *healthcare processes* and automate their execution through the use of dedicated Process-Aware Information Systems (PAISs). PAISs are able to interpret such processes and to deliver to doctors and medical staff (e.g., nurses, general practitioners) relevant information, documents and clinical tasks to be enacted, by invoking (when needed) external tools and applications [196]. Nonetheless, current BPM solutions, which are driven by predefined rules lists, have proven to be suitable to manage just the lower-level administrative processes, such as appointment making, but have made little progress into the core care procedures [219].

Based on the foregoing, the purpose of this research is to apply UCD approaches to design and develop digital services providing clinical PAIS, while investigating the multimodality of touch and vocal interfaces as a potential solution to reduce the cognitive load of doctors interacting with (clinical) mobile devices during the patient's visit, and a process-aware approach for the automation of a specific class of care procedures, called *clinical guidelines* (CGs). CGs are recommendations on how to diagnose and treat specifical medical conditions, presented in the form of "best practices". They are based upon the best available research and practice experience [308, 254, 103, 340]. It should be noted that the focus of this research is not on automating the clinical decision-making, but on supporting doctors in the enactment of CGs, delivering them the relevant clinical information (such as the impact of certain medications, etc.) to reduce the risk arising from a decision. The system exploits concepts from BPM on how to organize CGs and how to support their execution, in whole or in part. In addition, the system supports vocal and multi-touch interaction with the core clinical mobile devices. This allows the doctor to switch between different modes of interaction selecting the most suitable (and less distracting) one during a patient's visit.

To sum up, the system addresses a critical problem in smart healthcare spaces nowadays, which is handling the complexity of many medical tasks and activities including clinical assessment and treatment decisions while considering many complicating circumstances – often not easily predictable in advance – that may arise. The target is to demonstrate that the adoption of mobile devices providing multimodal user interfaces coupled with a process-oriented execution of clinical tasks represents a valuable solution to support doctors in the execution of CGs. Our proposed system is also referred to as TESTMED system because it was conducted in the context of the Italian project TESTMED (TESTMED was a 24-month Italian project, and stands for "*meTodi e tEcniche per la geSTione dei processi nella MEdicina D'urgenza*", in English: "*methods and techniques for process management in emergency healthcare*"). The TESTMED system has been designed through the User-Centered Design (UCD) methodology [121] and evaluated in the emergency room of DEA ("Dipartimento di Emergenza ed Accettazione", i.e., Department of Emergency and Admissions) of Policlinico Umberto I, which is the main hospital in Rome (Italy).

The rest of this chapter is organized as follows: Section 2 provides relevant background knowledge about healthcare processes and CGs, and introduces a concrete CG that will be used to explain the approach underlying the TESTMED system. Section 3 describes the research objectives of the TESTMED system and the general approach used for dealing with the enactment of CGs. In Section 4, recent relevant works are discussed including the role of BPM and PAIS to model and automate healthcare processes, the role of employing clinical mobile technologies while exploiting their integrated multimodality, and investigating the potential brought by vocal interfaces in general and in health support systems context in particular. Section 5 presents the architecture of the system, introducing technical details of its software components and implementation. Then, Section 6 presents the outcomes of the user evaluation of both the first and the second prototypes of the system and some performance tests. The final conclusion about the system's main findings, providing a critical discussion about the general applicability of the approach, and tracing possible directions of future work are discussed in Chapter 7 given the abstract context of user-oriented service digitalization and innovation.

2 Modeling Clinical Guidelines as Healthcare Processes – Chest Pain Case Study in Emergency Healthcare

2.1 Healthcare Processes

In the context of a hospital, the work of the doctors and the medical staff includes the enactment of several organizational and clinical tasks, which are organized in a care pathway customized for the patient to be visited. In addition, various organizational units are involved in the care pathway of a patient. For example, for a patient treated in the department of cardiology, general blood tests at the laboratory and a thoracic RX at the radiology department are required. This means that doctors from different departments must visit the patient, write medical reports and share the clinical results, i.e., all clinical tasks must be performed in certain orders and cooperation between different organizational units is required to properly achieve such tasks [273].

Based on the foregoing, it is possible to identify several *healthcare processes* having growing complexity and duration. For example, there are short organizational procedures like patient acceptance or long-running treatment processes like physiotherapy. According to [217], healthcare processes can be classified into two abstract groups: *elective care* and *non-elective care*.

- *Elective care* refers to clinical treatments that can be postponed for days or weeks [202]. According to [148], elective care can be classified into three subclasses: *(i) standard processes*, which are care pathways where the ordering of activities and their timing is predefined; *(ii) routine processes*, which are care pathways providing potential alternative treatments to be followed for reaching an overall clinical target; and *(iii) non-routine processes*, where the next step of the care pathway depends on how the patient reacts to a dedicated treatment [337].
- *Non-elective care* refers to *emergency care*, which has to be enacted immediately, and *urgent care*, which can be procrastinated for a short time.

To additionally understand the complexity of a healthcare process, it is possible to classify it in six macro steps [316], organized according to the degree of structuring and predictability they exhibit [290]. Figure 33 shows such a classification.

The six macro steps include:

1. *patient registration*, which consists of creating a medical case file;
2. *patient assessment*, where an initial diagnosis for the patient is performed;
3. *treatment plan definition*, which refers to the realization of (dedicated) individual care plan;
4. *treatment delivery*, which consists of enacting the clinical actions provided by the care plan;
5. *treatment review*, which consists of a continuous monitoring of the impact and efficacy of enacted treatments, in order to provide feedback for the previous steps;

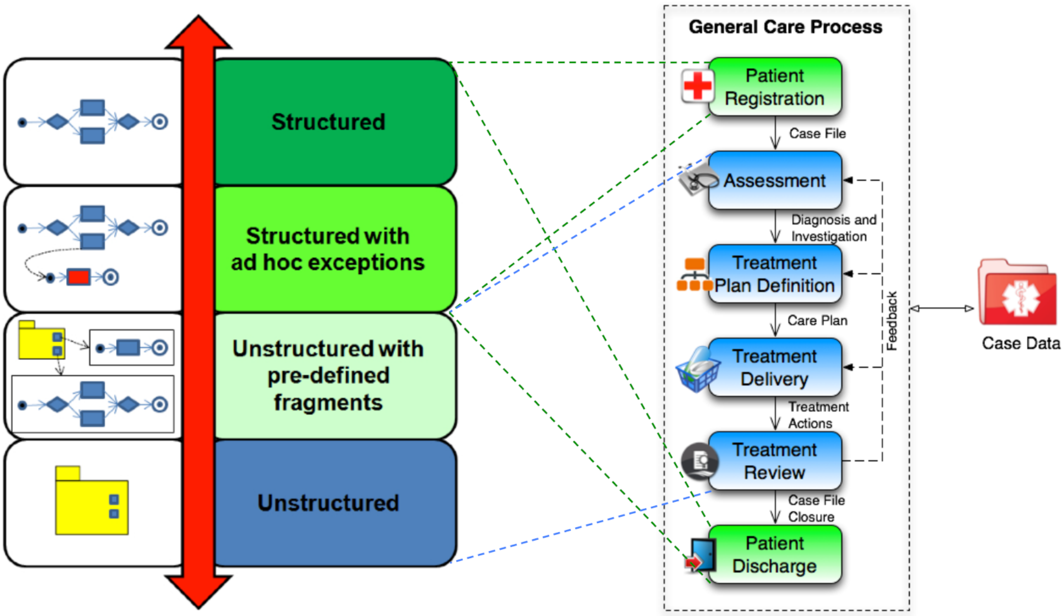


Figure 33. Classifying healthcare processes in six clinical macro steps.

6. *patient discharge*, consisting of the closure of the case file.

Administrative steps such as *patient registration* and *patient discharge*, as well as organizational activities such as lab tests and patient transfer, are typically structured and repetitive. Any potential exceptional behaviour is limited and can be anticipated at the outset. For this reason, they are good candidates for being enacted by traditional approaches for process management [273].

On the contrary, all the other diagnostic and therapeutic steps of the healthcare process can be seen as *knowledge-intensive activities*, since they depend on medical knowledge and evidence, on patient-specific and case data, and on doctors' experience and expertise. In these steps, patient case management is mainly the result of knowledge work, where doctors act in response to relevant events and changes in the clinical context on a per-case basis, according to so-called diagnostic-therapeutic cycles based on the interleaving between observation, reasoning and action [196]. Moreover, many complicating circumstances—often not easily predictable in advance—may arise during these steps enactment. For this reason, they typically lead to loosely structured or unstructured processes [116].

To sum up, the overall healthcare process, even in its oversimplified view of Figure 33, reflects the combination of predictable and unpredictable elements, making their complete automation through traditional Process-Aware Information Systems (PAISs) extremely complex, which tend to restrict the range of actions of doctors and medical staff too much [290].

Although it is clear that a gap exists between the process-driven techniques provided by the BPM community and the methodological-driven solutions suggested by the medical informatics field that is unlikely to be solved in near future [273], in this research, we discuss how a process-aware approach can be efficiently used to support the management of a specific class of care procedures, called *clinical guidelines*.

2.2 Clinical Guidelines

Over the last year, there was an increasing interest from the medical community to investigate and develop evidence-based *clinical guidelines* (CGs). CGs are based on the best available medical research evidence, and are represented in the form of recommended care pathways to support proper decision-making in patient care for specific medical conditions [254, 103, 253, 129]. Typically,

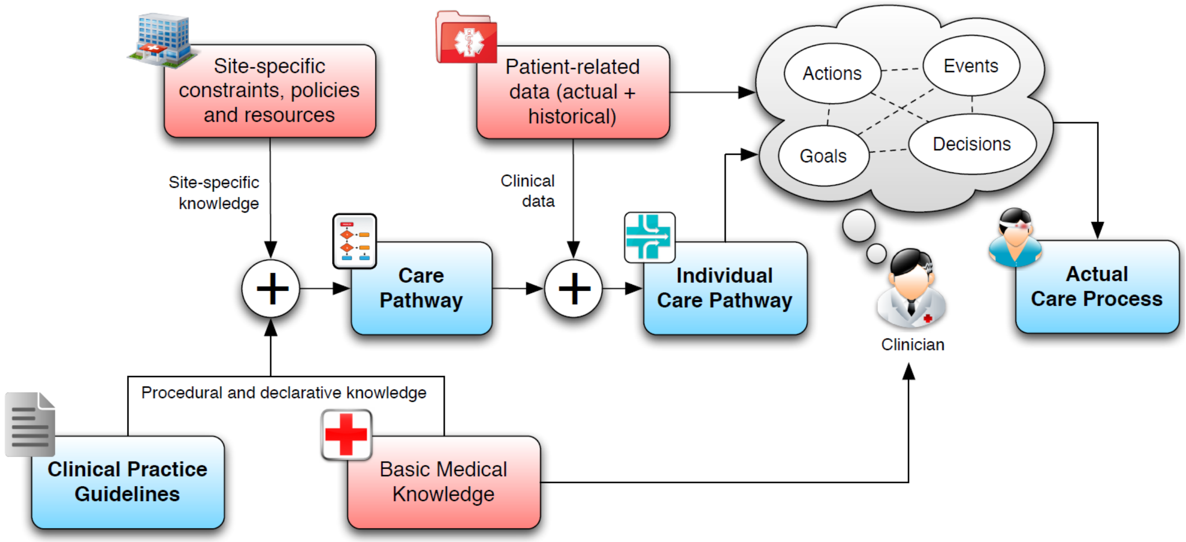


Figure 34. Transforming CGs into patient-specific care pathways.

a CG does not enforce mandatory requirements but is used as a reference framework for evaluating clinical practice.

As shown in Figure 34, CGs are defined to capture domain-specific knowledge, and need to be complemented by additional "knowledge layers" that include doctors' basic medical knowledge (BMK), site-specific knowledge and patient-related information (such as medical history and current conditions) to obtain concrete care pathways that can be applied to a specific patient. Care pathways suggest the required clinical activities, together with their sequencing and timing, for the management of patient conditions. According to [196], the combination of care pathways and patient-related information enables the definition of an individual care pathway, which results in the actual patient treatment process.

One strength of adopting CGs and care pathways in the management of patient care relies on their structuredness and process-oriented perspective, differently from traditional clinical decision-making that leads to loosely structured or unstructured working procedures. The research literature in the medical informatics community has deeply investigated the definition of models, languages and systems for the management of CGs and care pathways, focusing on the so-called "computer-interpretable clinical guidelines" (CIGs). The work [290] presents a recent survey classifying the existing frameworks for managing CIGs, which can be categorized as rule-based (e.g., Arden Syntax), logic-based (e.g., PROforma), network-based (e.g., EON) and workflow-based (e.g., GUIDE). Most of the available formalisms allow for representing CGs as task networks, where activities and decisions are related via scheduling and temporal constraints, often in a rigid flowchart-like structure. This has made the automated enactment of CGs using PAISs and process-oriented approaches as a relevant and timely challenge for the medical community [168, 273, 290].

In this research, we tackle this challenge by presenting the main findings of the TESTMED system, whose aim is to realize a clinical PAIS able to interpret CGs and orchestrate their execution among doctors and medical staff through mobile technologies and multimodal user interfaces.

2.3 Case Study: Chest Pain

For a better comprehension of the TESTMED system as a whole, in this section, we provide details about a standard CG enacted for patients suffering from chest pain. Chest pain is defined as a pain or discomfort that is felt anywhere along the front of the body between the neck and upper abdomen. It can be an indicator of a possible heart attack, but it may also be a symptom of another disease. Chest Pain is considered as one of the most common reasons for the admission in the emergency room (5% of all visits) with high mortality in case of diagnosis failure and improper dismissal

(2–4%) [247]. When a patient suffering from chest pain reaches the emergency room, typically s/he is visited by a doctor, who investigates the patient history and the risk factors. Furthermore, a *chest pain score* is calculated, which enables the doctor to classify patients into low and high-risk subsets for cardiac events.

Figure 35 shows the chest pain score adopted by DEA. The score is derived from a set of four clinical characteristics: *(ii)* the *localization* of the pain; *(ii)* the *character* of the pain; *(iii)* the *radiation* of the pain and the *(iv) associated symptoms*. A partial score is associated with each characteristic, and the sum of these values produces a final score that predicts the angina probability. A chest pain score lower than four identifies a low-risk probability of coronary disease, whereas a score greater or equal than four can be classified as an intermediate-high probability of coronary risk, i.e., it is required to admit the patient for clinical observation. Different values of the rate correspond to different clinical treatments to be followed by the patient.

Chest Pain Score	**Score**
Location	
Substernal, precordial	+3
Left hemitorax, neck, jaw, epigastrum	+2
Apical	-1
Character	
Crushing, pressing, squeezing	+3
Heaviness, tightness	+2
Sticking, stabbing, pinprick, catching	-1
Radiation	
Either arm, shoulder, back, neck, jaw	+1
Associated symptoms	
Dyspnoea, nausea, diaphoresis	+2
Score < 4: Low probability of angina pectoris	
Score ≥ 4: Medium-high probability of angina pectoris	

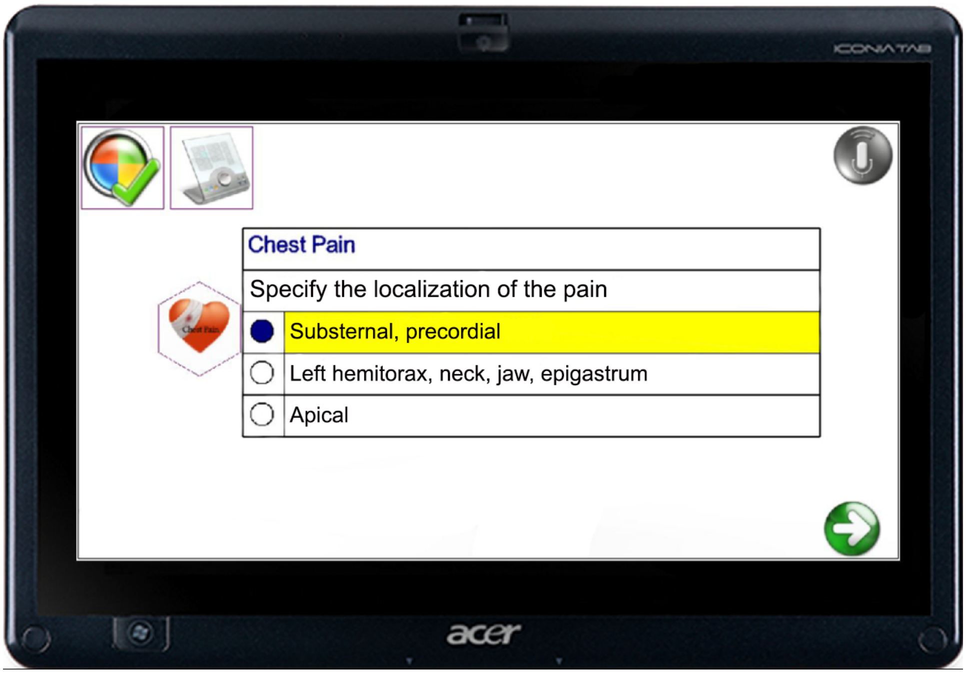
Figure 35. The list of clinical characteristics to calculate the chest pain score.

3 Research Objectives: Investigating a Patient-Centered Operation of Clinical Guidelines

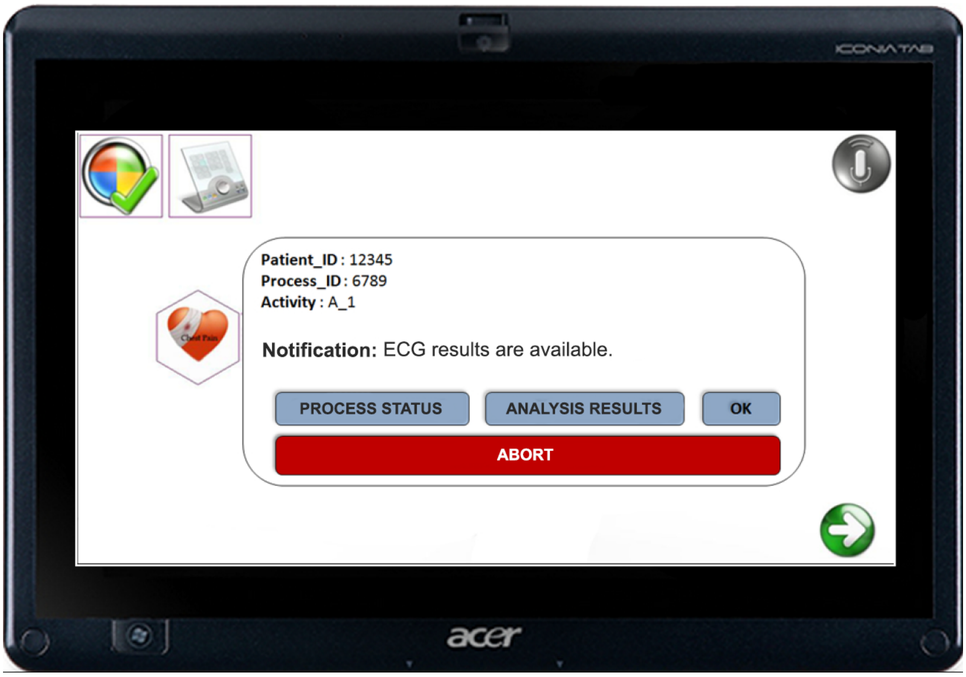
The main challenge tackled by the proposed system is to reduce the gap between the fully automated solutions provided by the BPM community and the clear difficulties of applying a traditional process management approach in the healthcare context. To realize this vision, the major outcome of this research is the development of a clinical PAIS, referred to as a TESTMED system, enabling the interpretation and execution of CGs and their presentation to doctors and medical staff through multimodal user interfaces.

The TESTMED system is thought to be used when a patient suffering from a medical condition (amenable to a CG) asks for a visit. Doctors are provided with a tablet PC (supporting touch and vocal interaction) that runs the TESTMED system. Thus, the doctor is enabled to select, instantiate, and carry out specific CGs.

For example, in the case of chest pain, the doctor starts filling a survey for determining the severity of the patient's medical condition, which is expressed through a chest pain score (cf. also Section 2.3). The survey is presented to the doctor on the graphical user interface (GUI) of the tablet PC where the TESTMED system is installed (see Figure 36a). The interaction can be performed by exploiting the touch features of the tablet, or, vocally, through integrated speech synthesis and recognition. The grey icon with a microphone that is located at the top-right of the



(a) A question included in the survey to calculate the chest pain score.



(b) Notification of the results of a lab analysis.

Figure 36. The multimodal GUI adopted by doctors.

GUI in Figure 36a is shown only when the interaction shifts from touch to vocal. It serves as a visual feedback that the vocal interaction is properly working.

The vocal interaction requires that the doctor wears a headset (The use of a headset guarantees both a higher quality of the vocal interaction in a noisy environment like the hospital ward's one, and that the privacy of the visited patient is preserved) with a microphone linked to the tablet; s/he can listen to the questions related to the survey and reply vocally by choosing one of the speech-synthesized possible answers. Each answer is associated with a specific characteristic and provides an associated rate.

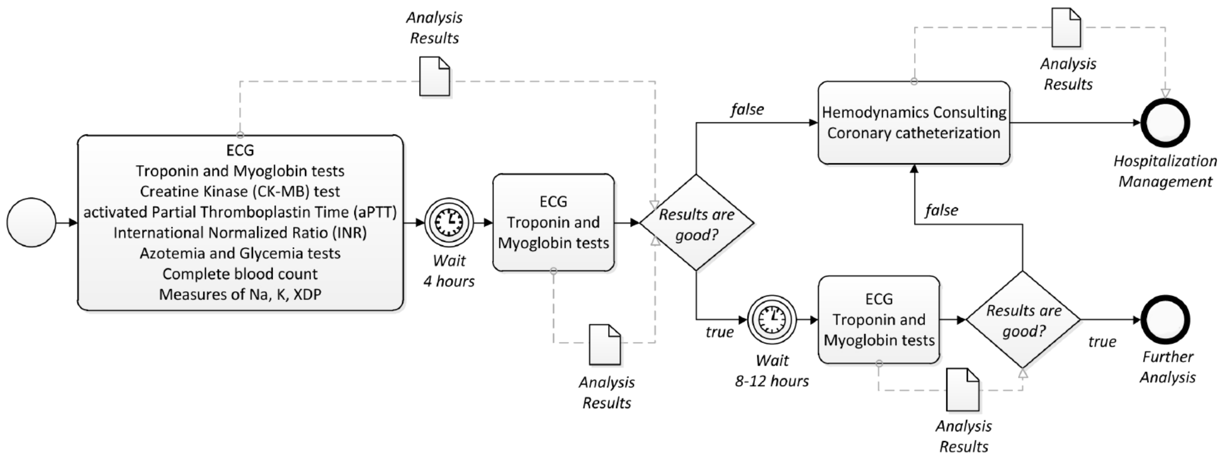


Figure 37. A care pathway for chest pain represented as a BPMN process.

Once the survey is completed, the TESTMED system elaborates a dedicated therapy including a sequence of clinical treatments and analysis prescribed to the patient. The therapy is structured in the form of a *care pathway*. As an instance, when the chest pain score is greater than 4, the suggested care pathway is the one shown in Figure 37. For the sake of readability, we have modeled the care pathway in the *Business Process Modeling Notation* (BPMN is a standard ISO/IEC 19510:2013, cf. https://www.iso.org/standard/62652.html, to model business processes). The reader should notice that BPMN is not the notation employed to concretely represent and encode a CG in the TESTMED system (to this aim, we used PROforma language [315], as explained in Section 5), but it is used here to show (in a comprehensive way) how care pathways usually look like.

The care pathway in Figure 37 includes, first of all, that the patient is subjected to some general blood analysis, which must be repeated for a second time after four hours. Once the analysis results are ready, the doctors assess them to decide if the patient should be hospitalized or not. Specifically, if the results are not good, the care pathway in Figure 37 provides instructions on performing further tests to the patient (in this case, a hemodynamics consulting and a coronary catheterization) and, based on the results obtained, to activate a further procedure concerning the hospitalization of the patient. On the other hand, if the analysis results are good, after 8–12 h, the patient is subjected (again) to some general blood analysis, whose results drive the next clinical steps to be performed to the patient, according to the care pathway in Figure 37.

The enactment of the various clinical tasks takes place in different moments of the therapy. Furthermore, a collaboration between doctors and medical staff is crucial to enact the proper medical treatments for each patient. The components of the medical staff (i.e., nurses and general practitioners) are equipped with Android-based mobile devices and are notified of the progress of care pathways and of the clinical tasks that have to be enacted for supporting doctors (e.g., to perform a blood analysis to the patient, etc.). Figure 38 shows two screenshots of the GUI provided to the medical staff, which only allows for tactile interaction.

The TESTMED system provides the ability to properly orchestrate the clinical tasks, assigning them to (available) doctors or members of the medical staff, and to keep track of the status of the care pathway, by recording the results of the analysis and and doctors' decisions. Reminders and notifications alert doctors and the medical staff if new data (e.g., the results of some analysis is ready to be analyzed—see Figure 36b) are available for some patient. If this is the case, the doctor can decide to visualize further details about the analysis results and the execution status of the care pathway or simply accept the notification. It is worth noticing that the doctor can abort the enactment of the care pathway in any moment.

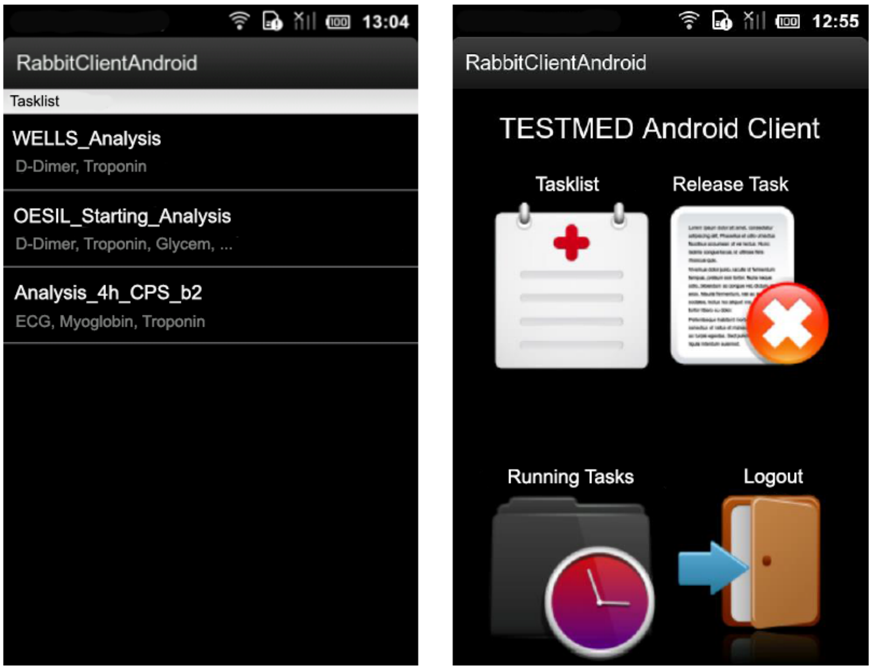


Figure 38. The GUI deployed on the mobile devices adopted by the medical staff.

4 Related Work

4.1 Process-Oriented Healthcare Systems

Notwithstanding the huge achievement of employing PAISs in many recent industrial projects together with adopting fast-growing process-oriented methodologies in various real-world scenarios [109, 223, 224], BPM technologies are still facing several challenges to be widely adopted in healthcare applications [196, 290]. This is mainly due to the rigid structure imposed by PAISs on the process definition that restricts the flexibility of handling and managing healthcare processes, which are often affected by many variations and exceptions during their enactment [102]. To tackle this issue, BPM technologies should evolve in a way that enables an enhanced flexible management of healthcare processes, while—on the contrary—the recent research attempts are more focused to improve their automation on top of the existing PAISs [273].

In this direction, the work [218] identifies the different flexibility requirements that can be empowered by employing process management technologies in healthcare applications. The focus of this work relates to the diagnostic steps of a gynecological oncology process and its possible implementation in four different PAISs. However, the work [218] is mainly oriented to analyze flexibility requirements for well-structured healthcare processes.

The work [283] investigates the modeling of pathology processes for programmed surgical interventions using the BPMN notation. The designed models include all the clinical activities required not only during a surgical intervention, but also in the preparation/follow-up phases, which take place before/after the intervention. Note that, in [283], no supporting system for process enactment is discussed. Similarly, the work [312] defines several clinical processes in BPMN that cover all the therapy steps of a patient, from the moment of the admission in the hospital to the leaving.

A wider investigation about the promising role of BPMN for modeling healthcare processes is addressed in [288], where challenges like the multi-disciplinary nature of healthcare processes and their interoperability requirements for being executed in traditional PAISs are discussed. In [196, 38], the authors consider again interoperability requirements together with service coordination and application integration as basic assets to achieve the required support to enact healthcare processes.

In particular, they notice that current information systems employed in healthcare applications consist of several independent (clinical) department systems, leading to many integration issues. Despite the use of the HL7 standard mitigating such integration issues, in [196, 38], the authors advocate that a commonly agreed solution that guarantees a proper integration between different clinical systems is still missing.

In [217], the authors investigate how the use of process mining techniques can enhance the functionality of EHR applications exploiting the knowledge contained in their events' logged data while addressing various issues regarding costs and efficiency of healthcare processes management. According to [328], process mining can be classified into three major branches: *(i)* process discovery [331, 329, 43], *(ii)* conformance checking [330, 104, 108, 105, 107] and *(iii)* process enhancement [214, 128, 215]. Specifically, in [217], the authors argue that the enhancement of healthcare processes is directly linked to understanding the "nature" of these processes. This can be done by identifying what happens in the whole healthcare procedures (i.e., process discovery) and analyzing if they present inconsistencies or deviations with respect to the expected therapies they aim to deliver (i.e., conformance checking). Finally, inefficiencies, bottlenecks, and other issues can be detected and fixed employing process enhancement techniques.

Given a service-oriented architecture that leverages the utilization of web services, some systems have been presented to address the issue of enacting healthcare processes through the definition of service orchestration specifications as BPEL (Business Process Execution Language) processes. For example, in [39], the authors introduce an innovative way to create web service specifications in BPEL exploiting a semi-automated model-driven approach that focuses on the administrative workflow including medical tests scheduling and tracking patient's status from admission to discharge. Similarly, service-oriented integration, web services, and process technology are also discussed in [212] as a means to automate healthcare processes in their inter-organizational emergency scenarios. In [263], the discussion of [212] is enlarged to mobile technologies and cloud-based architectures.

In [197], the Serviceflow Management system is presented as a tool to manage entire healthcare processes, in particular when several organizational units are involved in the care delivery activity. The system provides a three-level architecture, where the upper level is the one responsible for coordinating the services available in the lower levels and handling the whole healthcare process, which is modeled as a Serviceflow. Finally, in [213], authors present an approach to support healthcare processes via a service-oriented architecture. The approach focuses on organizing the operations performed in a sterile processing department as a healthcare process, and identifies the needed architectural requirements to realize a system supporting such process. The proposed architecture is prototyped and evaluated in a sanitation working area.

If compared with the above works, which mainly provide ad hoc solutions for managing well-defined healthcare processes, the aim of TESTMED is to realize a general-purpose clinical PAIS able to interpret CGs encoded in the PROFORMA language and orchestrate their execution among doctors and medical staff through mobile technologies and multimodal user interfaces.

4.2 Mobile and Multimodal Interaction in the Healthcare Domain

Mobile and multimodal user interaction have a long history of success in many real-world settings, including emergency management [78, 160, 222], smart and collaborative environments [209, 67, 171, 162], cultural heritage [346, 95], and—of course—healthcare [86]. When it is employed properly, such technology can contribute not only to improve patient care delivery, but also to push towards a large adoption of mobile clinical devices in hospitals.

In this direction, in [135], Flood et al. propose a method that allows designers and developers of medical mobile applications to evaluate the implemented prototype of their applications early, in particular if their usage might produce a high cognitive effort on the end users. The proposed method includes the interruption of the application development process and the modification of the user interface design when required. Although this methodology is oriented to mitigate the perceived cognitive efforts during the usage of mobile applications, it does not introduce any novel design technique that tackles the issue of mobile multimodal interaction. Conversely, in [175], Jourde et al. acknowledge the importance of providing multimodal interactions with clinical mobile devices by proposing a specification for designing user interfaces for a multimodal collaborative healthcare system. Another interesting approach is the one proposed by [232], which consists of a smart mobile device with a software system supporting mobile interaction that handles auditing tasks and empowers medical staff of emergency rooms to establish seamless clinical handover procedures. Finally, the GuideView system [169, 170] suggests the importance of adequate mobile interactions for astronauts in their space exploration missions, especially when they need to deliver medical care to themselves, in situations where professional medical assistance from earth is impossible. It is worth noticing that none of the above works are intended for improving CG modeling or execution.

To summarize and confirm what was stated in Section 1, the TESTMED system aims to provide the following requirements: ensuring information flow continuity by supporting mobile access to information, empowering doctors while executing CGs, and improving and sustaining effective design of mobile multimodal interaction in order to alleviate the physical and cognitive overload on the medical staff and doctors. The recent works including the above-mentioned ones have mainly targeted just a single requirement or a partial combination of them.

4.3 Vocal Interfaces

Computers' input and output interfaces have been evolving in the last few years to provide humans with an improved user experience while interacting with and collaborating through computers during different kinds of tasks. One of the drivers of this evolution is providing interfaces that exploit all human senses, with a particular emphasis given to visual, verbal, and tactile interactions, which are considered to provide the most realistic dialog between the human and the computer. Thanks to the recent maturity and wide availability of smart mobile devices, which have become smaller, more portable, and more powerful, the call for more effective interfaces besides traditional ones has become even more urgent. As a consequence, there are a considerable number of recent research works discussing current limitations and possible opportunities about the so-called multimodal interaction. Involved technologies include haptic devices, such as digital pen, fingerprint scanners and 3D gestures, and advanced vocal and visual interfaces such as voice commands and face recognition. In particular, these technologies must be integrated with the aim of providing target users with the interaction that best suits their needs.

Vocal interfaces represent a widely employed interaction model, demonstrating their usefulness in various scenarios such as home automation, car driving and manufacturing processes. In an early patent [228], authors developed an interactive speech application in the context of telephone systems, where interactive dialog tasks with users (i.e., callers) can be defined in the form of dialog modules where user input is provided in the form of verbal commands. The very same approach can be employed in the context of smart mobile devices where display screens are relatively small and vocal input would support easier, faster and more efficient task execution compared with the sole employment of the touch interface. An example of this approach is presented in [154], where authors suggested to use a voice-controlled interface to overcome the task of reading large amounts of text (e.g., selection menus) and typing responses using a small touch keyboard. The work presented in [300] considers the case of crisis management and suggested that providing multimodal interfaces including vocal interaction would be highly valuable in such environments, leading to solving issues in a shorter time while ensuring a better collaboration among team members. On the other side, authors in [262] analyzed the performance of available automatic speech recognition (ASR) techniques and indicated the required level for speech to become a truly pervasive user interface. The employment of new, very precise, recognition techniques, based on neural networks has finally made the employment of voice based interface ubiquitous.

Recently, many commercial prototypes of vocal interfaces have been introduced in the market. This can be easily noticed in many mobile operating systems, where the vocal interface (as a natural language user interface) is provided to serve as an intelligent personal assistant and knowledge navigator. Such systems include Siri, Google Assistant and Cortana. These programs listen to user vocal input, interpret it as verbal commands, and respond back to the user using text to speech, thus imitating human-to-human vocal interaction. Unfortunately, when the system was developed, these systems were not available, so we employed the Text-To-Speech (TTS) engine and the Microsoft Automatic Speech Recognition (ASR), as discussed in Section 5.

In the context of health support systems, vocal interfaces have been employed in several applications. Authors in [152] suggested using the audio input after detecting the fall of elderly persons who live alone. Here, the system is implemented on a mobile device and an accelerometer is used to identify a suspected fall. At that point, the user can ask for immediate help vocally, as typing using the keypad could be impractical in such a critical situation. Similarly, following the direction of tele-home health care, authors in [207] examined the use of voice as a means for obtaining patients' emotions while being monitored remotely, which is a context where even a higher level of skills, professionalism, and competence is needed with respect to an in-person visit. Here, authors pointed out that detecting patients' emotions using the voice could be even more accurate, as patients themselves find difficulties to express precisely their own state of feeling, and therefore emphasized the importance of developing such multimodal intelligent effective interface. A similar work was conducted in the field of psychopathology [94], where clinical diagnosis of major depression cases was applied using facial expressions and voice analysis to help automatic detection of depression whose assessment is usually based on classical reports (e.g., clinical interviews and questionnaires).

Authors in [240] discussed the employment of robots in healthcare structures (e.g., hospitals), and proposed to apply vocal interaction with robots moving around the healthcare center, for better and efficient execution of tasks in such environments.

In their work of presenting multimodal integration of continuously spoken language and continuous gesture, authors in [93] included in their prototype an example of medical informatics in which users (patients in this case) can search using speech and gesture for available healthcare providers on a map of their zone. The multimodal input in this prototype is translated into a query that is executed on the database of all healthcare providers (e.g., doctors) in the selected area, and retrieve back results that can be then showed directly on the map. In the attempt of establishing a health-aware smart home that serves as an intelligent space assisting elderly and users with special needs in their daily life activities, authors in [134] argued that voice interfaces can be helpful as they do not require to be worn or to be spatially close to any device.

In the context of navigational assistance for surgical interventions, authors in [57] developed a prototype that uses virtual reality together with a multimodal interface (including vocal input) and an expert system that helps to infer context in order to provide support for surgeons, either in a process simulation or in a realistic intervention, and for both training and clinical purposes.

Our work can be positioned in this research context, where the introduction of a mobile application, which supports conducting the needed related clinical guidelines while providing a multimodal interaction with a vocal interface, can lead to significant benefits for both patients and clinicians. These benefits can be easily noticed when clinicians working with these IT systems use the vocal input in a hands-free mode, which in turn allows for conducting the healthcare tasks easier and faster in such environment and helps medical staff while they physically examine their patients in order to improve the overall clinical performance.

5 System Architecture and Implementation

After identifying the main objectives and challenges in our research topic concerning the requirements to realize a clinical PAIS able to interpret CGs and orchestrate their execution efficiently among doctors and medical staff through mobile technologies and multimodal user interfaces (while considering chest pain as our main case study), and after surveying and analyzing the recent related work in the state of the art, we will proceed to present our methodology to deliver the mentioned objectives and tackle the corresponding challenges. In this sense, and complying with

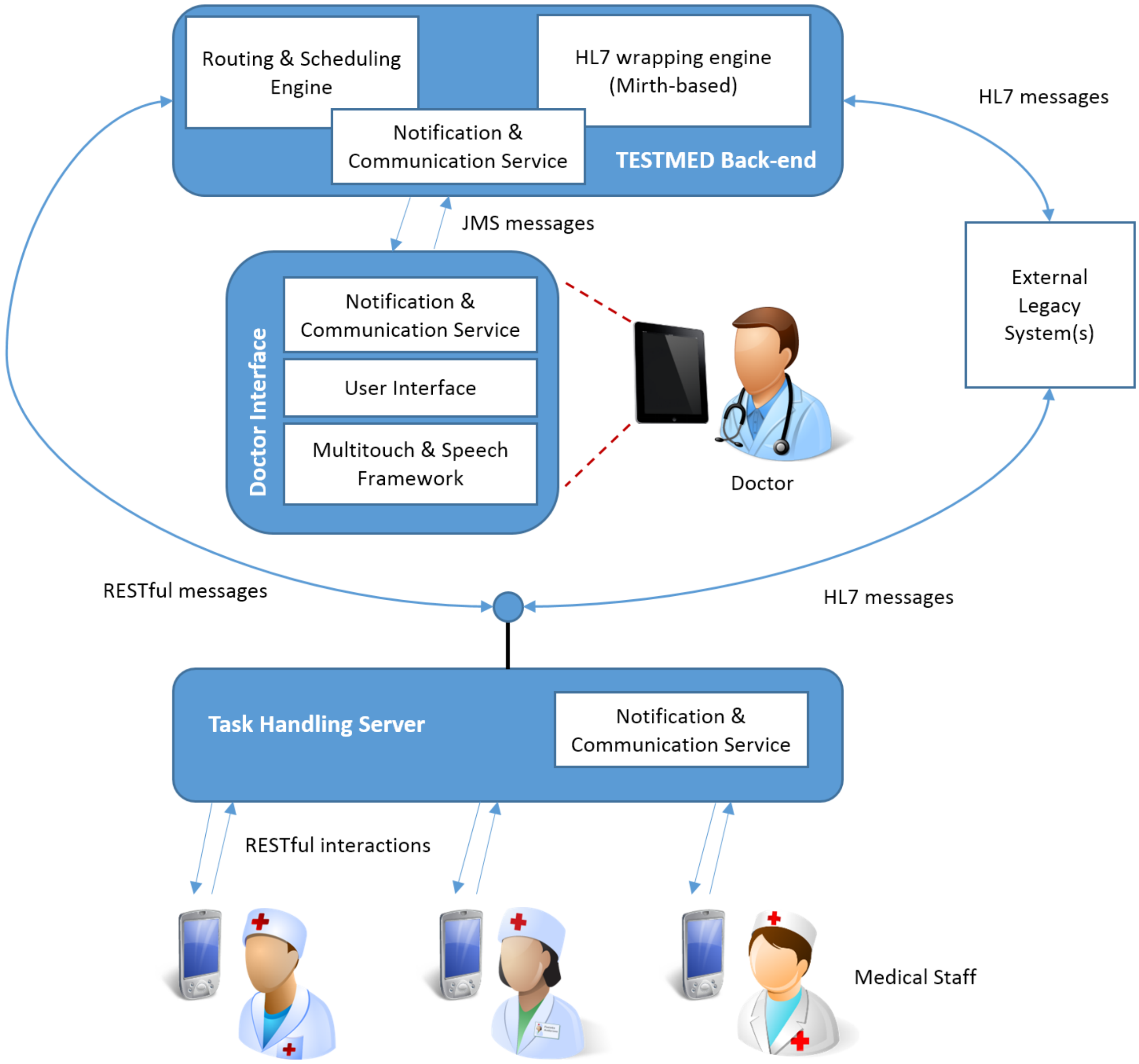


Figure 39. TESTMED system architecture.

these requirements and the related demands in healthcare sector, we employ the UCD approaches throughout the whole implementation process of the proposed prototype while trying to overcome some UX challenges and limitations in order to enhance the UX characteristics of the system. We will start by defining the architecture of the suggested system while discussing the implementation of all the system parts as designed for a workable running prototype.

The TESTMED system is based on three main architectural components: a *graphical user interface*, a *back-end engine*, and a *task handling server*. Figure 39 shows an overall view of the system architecture.

The system is implemented employing a multimodal user interface. On the one hand, doctors interact with a GUI (see Figure 36) that is specifically designed for being executed on large mobile devices (e.g., tablets), and allows for tactile or vocal interaction. In particular, vocal interaction enables doctors to work flexibly in clinical scenarios where their visual and haptic attention (i.e., eyes and hands) are mainly busy with the patient's visit. On the other hand, the GUI provided to members of the medical staff is thought to be visualized on small mobile devices (e.g., smartphones) and provides only a tactile interaction (see Figure 38).

The *back-end engine* with its services provides the ability to interrupt, activate, execute and monitor CGs and relevant data between doctors and the medical staff at run-time. In TESTMED, a collection of various programming languages is used to define each CG. First, the PROforma language [315] is utilized to fulfill the role of modeling each CG into a set of clinical activities, data items, and the control flow between them. Then, starting from the resulted PROforma model, a configuration file is semi-automatically built in XML language to define all the necessary settings by which the multimodal interaction functionality is allowed and the integration of different system components is enabled. As a result, a CG will be finally represented as a *guideline bean*, which will be deployed into the system and ready for execution.

The execution of CGs is completed with a precise routing of data, set of events and clinical activities, which all follow a well-defined process-aware and content-based approach in which activities are scheduled and messages are dispatched in an event- and data-driven way. The back-end engine manages and controls the routing process of all clinical activities, related data, and produced events between the corresponding parts including actors, services, and applications. Therefore, it guarantees a successful interaction among all participating units and services. Moreover, any software module that communicates with the engine for completing any defined activity can be viewed as an external service to be invoked when needed.

Basically, services are considered wrappers over pre-existing legacy systems, such as the Electronic Medical Record (EMR) systems employed in hospitals.

The routing engine performance depends on a primary scheduling unit which handles the accomplishment of activities that require temporal constraints (e.g., examinations and analytical experimental tests which should be designed and conducted in a timely manner), and communicates with the EMR system in order to *(i)* search and query medical and administrative patient information, *(ii)* organize and plan examinations, laboratory tests, medicine receipts, etc. according to the related medical procedure, and *(iii)* get notified about events and laboratory testing results so that it can be forwarded to the assigned doctors. This interoperable work with the EMR system is realized by employing the Health Level 7 (HL7) standard protocol (HL7 is a set of international standards for transfer of clinical and administrative data between hospital information systems. http://www.hl7.org/). The analyzing, processing and creation of HL7 messaging packets is organized and controlled by a specific HL7 processing unit.

It is worth noticing that all the conducted activities while performing a CG should be stored and registered, in order to keep track and retrieve accordingly all the events, activities and data, which relate to the medical case and its decision-making scenarios. This registered information might be potentially utilized for: *(i)* creating medical and analytical reports; *(ii)* documenting the suggested and followed care plan assigned to each patient so that it can be used as a legal reference in the future; *(iii)* providing a database platform that maintains all the medical records and chosen treatment scenarios for all patients, which can be exploited to introduce a better and improved version of the documented CG after running further analysis on all these collected data; and *(iv)* providing valuable support for forensic analysis [304].

From a technical perspective, the multimodal interaction feature is developed with the utilization of different technologies including the Text-To-Speech (TTS) engines, the Microsoft Automatic Speech Recognition (ASR) and the Multi-touch for Java framework (MT4j, http://www.mt4j.org/). As for the back-end, it is implemented using the Tallis engine (http://archive.cossac.org/tallis/Tallis_Engine.htm), which is able to handle and manage the compatibility with the legacy systems installed in the hospital Policlinico Umberto I. This compatibility is facilitated and deployed using HL7 messages over Mirth (http://www.mirthcorp.com/products/mirth-connect). Each of the above-mentioned software parts is J2EE-based and hosted on a TomEE (http://tomee.apache.org/apache-tomee.html) application server. In particular, the communication between the back-end and the GUI of the assigned doctor is performed by a JMS-based notification engine, called RabbitMQ (http://www.rabbitmq.com/). Finally, Apache Camel (https://camel.apache.org/) is used as rule and mediation engine in order to orchestrate all the above technologies and components.

Finally, a *task handling server* is in charge of communicating with both the back-end and the existing legacy systems via HL7 and RESTful messages. This server has the important role of informing the medical staff about when a clinical activity is needed to be performed in the context of a specific CG. On the other hand, medical staff members, as previously discussed, are provided with a dedicated front-end Android application that employs RESTful services to interact with the task handling server.

All the logic of a CG is therefore coded via the PROforma model and various XML-based configuration files. Those files describe the data to be provided by the user interfaces, the queues and messages (JMS and HL7) to be exchanged, the routing and the scheduling of the different interactions, etc. (In particular, all those files instruct the routing and mediation rules enacted by the Apache Camel framework.) All these files are bundled in a *guideline bean*—a zipped archive that is then disassembled by the system and used to instruct the different components. For each new guideline to be deployed and enacted by the system, a new PROforma model and related XML-based files should be produced by the system engineer, on the basis of the BPMN process describing the care pathway (as the one of Figure 37 for the chest pain). Therefore, analogous to many middleware technologies and process-aware tools, the TESTMED system is general-purpose (no new code should be written when deploying a new CG) but requires technical configuration by system engineers, who, on the basis of the requirements of the specific care pathway to be implemented, design and deploy the guideline bean.

6 User Evaluation and Results

After implementing a prototype of the system following the discussed architecture in Section 5, a user study evaluating the UX of the system and the provided digital service is conducted. In this section, we describe the design and details of the conducted evaluation study. It aims to analyze users' (i.e., doctors and medical staff) behaviors and interactions while using the TESTMED system providing the required CG as a digitalized clinical service in a smart healthcare space for the case study of handling chest pain in emergency rooms.

To this extent, the TESTMED system has been thought to be used in hospital wards for supporting doctors in the execution of CGs. In this context, medical staff and doctors must work in collaboration and coordination to perform the appropriate clinical activities to the patients. Hence, providing a satisfactory mobile interaction is crucial, as it allows for:

- supporting the mobility of doctors for visiting the patients;
- facilitating the information flow continuity by supporting instant and mobile access;
- speeding up doctors' work while executing CGs and performing clinical decision-making.

The latter point is also confirmed by a survey carried out by the Price Waterhouse Coppers' Health Research Institute (HRI) [98], which reported that 56% of doctors—over a large sample—were able to improve and speed up their decision-making thanks to the use of mobile technologies.

Despite the utilization of mobile devices and applications may significantly empower the ability of doctors and medical staff to collaborate and coordinate themselves, there are still some key challenges to be addressed. One of these issues is the ability to provide a suitable GUI that can represent the nature of the related clinical tasks whose description can be highly sensitive and their time constraints are difficult to set. After having all the characteristics of such clinical tasks understood and analyzed, it is still required to invent a compact design with high usability standards, which best reflects all the relevant analyzed information while grasping direct users' attention in very limited context so that the main focus will be on the patients (i.e., a design which does not distract the doctors while visiting the patients), and therefore, supporting the required patient-centered operation of CGs and their related clinical tasks/activities [86].

To achieve this objective, we realized the TESTMED system leveraging the *user-centered design* (UCD) methodology [121], which places the end users at the center of any design and development activity. To this end, we initially developed two mockups of the system (during months 4 and 9 of the project, respectively). Various usability studies (including thinking aloud techniques, focus groups, etc.) have been conducted on each mockup with real doctors, and the results of each user study have been used for incrementally improving the design of the GUI of the system. One of the main effects of applying UCD methodology was the introduction of the vocal interface in the second mockup, together with the basic touch interface that was solely presented in the first mockup. This was due to the fact that the users' feedback on the first mockup indicated the need for the doctors to have their hands free while visiting a patient. That's why we introduced the possibility to (also) vocally interact with the GUI.

On the basis of the outcomes of the above usability studies, we have iteratively produced two working prototypes of the system in months 12 and 18 of the project, respectively. We assessed them employing well-established evaluation methods involving the target users (i.e., real doctors). Results and findings of the user evaluation performed over the working prototypes are discussed in the next sections.

In particular, this evaluation study is performed as a controlled experiment that measures various case-related usability parameters and metrics (e.g., ease of use), and the results are analyzed to validate good usability of the proposed system. The selected tasks of the experiment are chosen carefully to reflect on the actual use cases of the system and reveals its usability features and characteristics. According to the target scenario (cf. Section 2.3), the system focuses specifically on facilitating the work of doctors collaborating with other medical staff to execute the defined chest pain CG deployed as a digital service on their clinical mobile devices while providing a satisfying interaction.

Overall, the evaluation analysis follows a mixed-method approach combining quantitative (e.g., GUI scene transition time) and qualitative (e.g., users satisfaction) measures, and the measured variables in this experiment are related but not limited to error handling, learnability, perceived ease of use, control, perceived usefulness, satisfaction, etc (other possible measurable UX-related aspects are already mentioned and detailed in Section 2.1). Besides, widely accepted models like TAM as well as the user experience research in the digital medical informatics can help to assess the experiential aspects of our system and explore the interdependencies between its constructs that lead to positive usability experiences that drive the required digital service innovation. The collected feedback of this evaluation study is meant to be utilized for a strategic design and enhancement of similar user-oriented technology-based innovative digital services.

6.1 Evaluation Setting and Results of the First User Study

The two developed working prototypes have been tested with patients suffering from chest pain (cf. Section 2.3), and therefore the related CG has been modeled, configured and deployed on the system to perform the testing.

The initial user study was performed in Policlinico Umberto I hospital in Rome with the help of the Department of Emergency and Admissions (DEA). In Figure 40, a doctor is shown using the TESTMED system to enact the CG on a patient simulator. In this experiment, five postgraduate medical students and two doctors participated in the study. Given a patient simulator that was supposed to reflect a real patient with chest pain symptoms, the participants were asked to use the TESTMED system to visit the patient according to the related CG (see Figure 40).

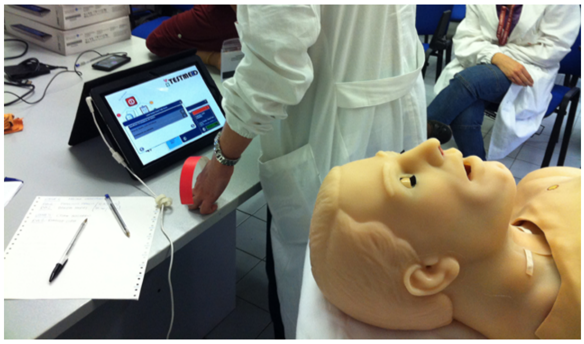
After the completion of the user testing, a questionnaire was provided to the participants with the aim to gather their background information and collect data about how they perceived the interaction with the system. Specifically, the questionnaire consisted of 11 statements covering aspects like easiness of use of the GUI, quality of the multimodal interaction, etc. The answers were evaluated through a 5-point Likert scale, which ranged from *1—strongly disagree* to *5—strongly agree*, to reflect how participants agreed/disagreed with the defined statements:

Q1 I have a good experience in the use of mobile devices.

Q2 The interaction with the system does not require any special learning ability.

Q3 I judge the interaction with the touch interface very satisfying.

(a)



(b)

Figure 40. A doctor using the TESTMED system in a ward during the visit of a patient simulator.

Q4 I judge the interaction with the vocal interface very satisfying.

Q5 I think that the ability of interacting with the system through the touch interface or through the vocal interface is very useful.

Q6 The system can be used by non-expert users in the use of mobile devices.

Q7 The system allows for constantly monitoring the status of clinical activities.

Q8 The system correctly drives the clinicians in the performance of clinical activities.

Q9 The doctor may—at any time—access data and information relevant to a specific clinical activity.

Q10 The system is robust with respect to errors.

Q11 I think that the use of the system could facilitate the work of a doctor in the execution of its activities.

Table 3.1 summarizes the results of the first user study. From such results, we can infer that the general attitude of the participants towards our system was positive. Results put in light that participants have considered the system as effective in the enactment of CGs, since it was able to concretely orchestrate doctors with executing the clinical activities included in the CG (cf. results of Q8). Furthermore, the system allowed doctors to constantly monitor the status of each clinical activity (cf. results of Q7) and to easily access information relevant to the specific activity under execution (cf. results of Q9). Participants also showed a fair amount of satisfaction with how the system behaves with respect to error handling (cf. results of Q10), learnability (cf. results of Q2), and ease of use for non-expert users (cf. results of Q6).

Table 3.1. Results of the first user study.

	Q1	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**	**Q7**	**Q8**	**Q9**	**Q10**	**Q11**
User1	4	3	4	3	2	3	4	4	4	3	3
User2	4	3	4	2	4	2	2	3	2	3	3
User3	5	3	4	3	5	2	5	4	5	4	4
User4	4	4	4	3	3	4	4	4	3	3	4
User5	3	3	4	2	3	4	4	4	4	3	4
User6	3	4	5	3	3	5	5	4	4	4	4
User7	3	4	4	3	4	4	5	4	4	4	4
Avg	3.7	3.43	4.14	2.7	3.43	3.43	4.14	3.86	3.71	3.43	3.71

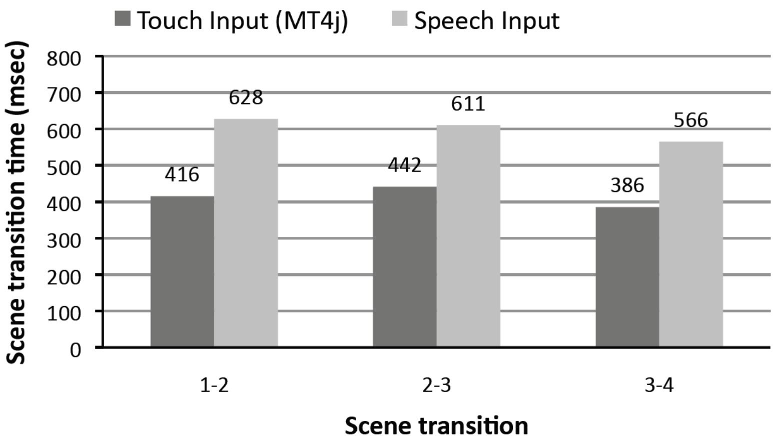


Figure 41. The vocal/touch user interface responsiveness tests.

On the negative side, the interaction with the vocal interface was considered as quite unsatisfactory (cf. results of Q4), while high satisfaction was experienced using the touch interface (cf. results of Q3). Nonetheless, the participants agreed that a multimodal interaction involving both touch and vocal interface could be useful to facilitate the work of doctors (cf. results of Q5). It is worth noticing that the questionnaire allowed participants to also add feedback and comments in free text. Using this feature, five out of seven participants explicitly asked us to develop an improved vocal interaction for the system, enabling doctors to dynamically switch the interaction modality (from vocal to touch, or vice versa) when needed.

The responsiveness of the GUI is another aspect that was investigated in the range of the first working prototype. In this direction, further tests were performed to calculate the time required by doctors to perform a single step of the survey associated with the CG deployed into the system (see also Section 2.3). Specifically, we assumed that a doctor completed a single step in the survey when s/he passed from one scene (in TESTMED, as discussed in Section 5, MT4j is exploited to build the GUI frames of the system, referred to as *scenes*, which enable to handle (multi)touch input events) of the GUI to the next one by answering the corresponding question of the survey. We monitored the time required by doctors to complete any scene associated with the CG's survey, until its completion.

We ran this test twice: firstly, using the touch interface, and secondly using the vocal interface. A summary of the collected results is shown in Figure 41, where each scene transition is represented on the x-axis, and the corresponding time required for generating the new scene and displaying it on the screen is on the y-axis. In our case study, which was focused on the chest pain CG, we needed three scene transitions before generating the final chest pain score.

The tests were performed using an ACER Iconia Tab W500 (ACER Inc., Xizhi, Taiwan) with a 1 Ghz AMD CPU and 2 GHz of RAM, which was running Windows 7 OS (Microsoft Redmond, Redmond, Washington, USA). With the exclusive use of the touch interface, the analysis shows an average time of 400 ms for completing a scene transition, compared to 600–700 ms required when just the vocal interface is used. The reason of the delay caused by using the vocal interface is due to the (extra) time needed by the system to contact the ASR engine (usually around 200–250 ms). Nonetheless, from the user point of view, this delay has a low impact on the overall responsiveness of the system, since timing that does not exceed 700 ms. to perform a scene transition is usually considered acceptable by the users [248].

6.2 Evaluation Setting and Results of the Second User Study

The results and findings of the first user study were leveraged to refine the weak aspects of the first prototype, in order to realize a (more) robust second working prototype of the system. If compared with the first prototype, the second one provided a more elaborated design of the GUI, together with a redefinition of the interaction principles underlying the vocal interface. For example, in the first prototype, the vocal features of the system were always active during the enactment of a CG. This resulted in many "false positives", i.e., the system wrongly recognized as proper vocal commands (by consequently activating unwanted functionalities) some words pronounced by the doctor during the patient's visit. In the second prototype, to prevent false triggers, we decided to activate the vocal interface only after a specific (and customizable) key vocal instruction pronounced by the doctor.

Leveraging the second working prototype, we performed a second user study employing the same chest pain CG used in the first user study. In addition, the second user study took place at the DEA of Policlinico Umberto I in Rome. Seven users (different from the ones that were involved in the first user study, i.e., following the between-subject controlled experiment design) participated in the second user study, including six postgraduate medical students and one doctor. Like in the first user study, participants attended the patient simulator and were asked to use the second prototype of the system to enact the CG (see Figure 40). They also completed the same questionnaire employed in the first user study to assess the effectiveness of the system. The results of this second user study are shown in Table 3.2.

Table 3.2. Results of the second user study

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11
User1	4	4	4	4	5	3	4	4	4	4	4
User2	4	4	5	3	5	2	3	4	2	4	3
User3	3	3	3	4	4	3	4	4	3	3	4
User4	5	4	3	2	4	5	5	4	4	5	4
User5	1	5	5	5	5	5	5	5	5	5	5
User6	3	5	4	5	4	5	4	4	4	5	5
User7	3	4	5	5	4	4	5	4	5	4	4
Avg	3.2	4.16	4.14	4	4.3	3.86	4.29	4.14	3.86	4.29	4.14

From the analysis of the results, it is evident that the good feelings obtained in the first user study about the working of the system have been confirmed by the results of this second user study. If we refer to Figure 42, we can note that participants' ratings in the second user study increased for all statements if compared with the first user study. Moreover, the results highlighted that the design of the second prototype made considerable progress, in particular because we precisely followed for its development the traditional design guidelines for building multimodal GUIs [192].

One critical aspect was the interaction with the vocal interface (cf. statement Q4), which resulted as being quite unsatisfactory in the first user study, with an average rating of 2,7. Conversely, the improved vocal interface employed in the second working prototype was really appreciated by the participants in the study, with an average rating of 4. To confirm that the improvement of the vocal interface was not the result of a coincidence, we analyzed the ratings for the statement Q4 collected in the first and second user studies leveraging the 2-sample t-test. This statistical test is applied to compare whether the average difference between two population means is really statistically significant or if it is due instead to random chance. The results of the 2-sample t-test are summarized in Figure 43. Statistical significance of the results is determined by looking at the p-value, which gives the probability that the collected results have been obtained randomly. If p-value assumes a value of 0.05 or less, it is possible to conclude that the collected data are not due to a chance occurrence, which is the case of our data (p-value is 0.0265099). This allows us to conclude that the improvement of the vocal interface was not the result of a coincidence.

Finally, we also performed a traditional System Usability Scale (SUS) questionnaire for precisely measuring the usability of the second working prototype. SUS is one of the most widely used

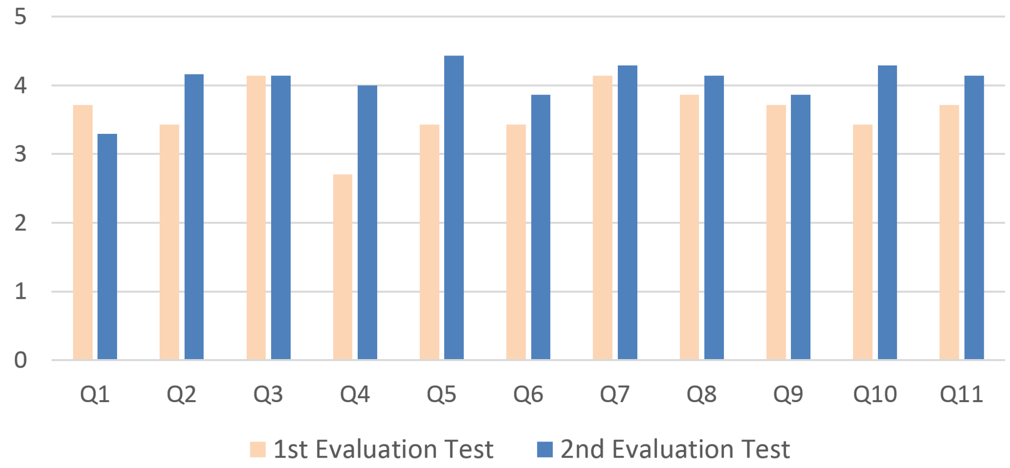


Figure 42. Comparison between the ratings obtained in the two user studies.

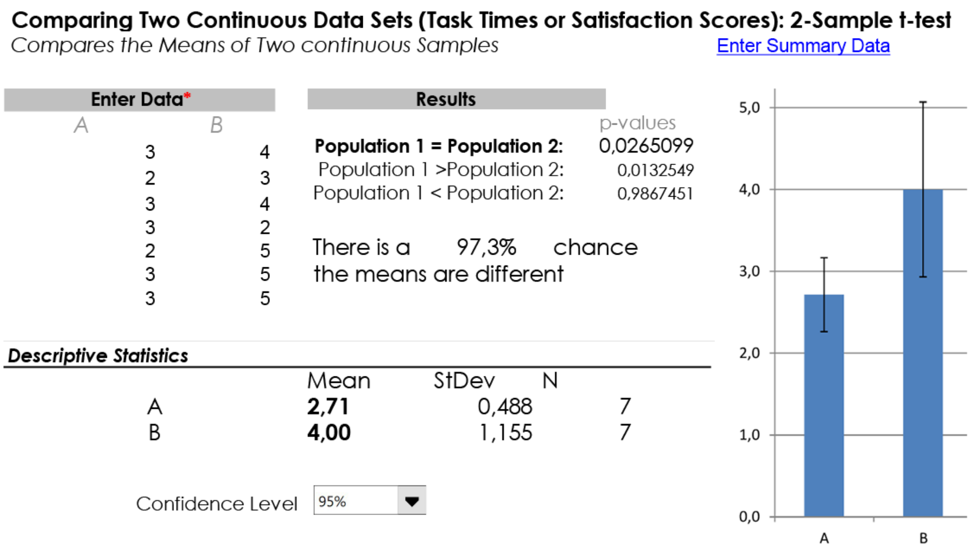


Figure 43. Results of a 2-sample t-test applied over statement Q4.

SUS Score Range	Grade	Percentile Range
84.1–100	A+	96–100
80.8–84	A	90–95
78.9–80.7	A–	85–89
77.2–78.8	B+	80–84
74.1–77.1	B	70–79
72.6–74	B–	65–69
71.1–72.5	C+	60–64
65–71	C	41–59
62.7–64.9	C–	35–40
51.7–62.6	D	15–34
0–51.7	F	0–14

Figure 44. A benchmark to evaluate the usability of a GUI.

methodologies for post-test data collection (43% of post-tests are of the SUS type [295]). It consists of a 10-item questionnaire. Any question is evaluated with a 5-point Likert scale that ranges from 1—strongly agree to 5—strongly disagree. Once completed, an overall score is assigned to the questionnaire. Such a score can be compared with several benchmarks presented in the research literature in order to determine the level of usability of the GUI being evaluated. In our test, we made use of the benchmark presented in [295] and shown in Figure 44. From the analysis of the SUS completed by the seven participants of the second user study, the final average ratings were of 77.5 and 78.4 for the GUIs used by the doctors and medical staff, respectively, which correspond to a rank of 'B+' in the benchmark presented in [295]. This means that the GUI of TESTMED has on average a good usability rate, even if there is still room for improvements.

Chapter 4

Power Saving as a Service: Realizing a User-Centered Digital Application for Automated Power-Saving Services in Smart Spaces

1 Introduction

Power Saving is conventionally regarded as the process of reducing the power consumption (i.e., the amount of power required) to operate specific utilities/devices by generally using less total power to fulfill the required functions/goals. As proposed by [227], this can be realized either by effectively reducing the amount of power used over time (e.g., using the heating system for a shorter time during the day to regulate room temperature) or by using the power resources more efficiently (e.g., using a heating system that consumes less power to give the same amount of heat).

Following this definition, this research focuses on the first option of reducing the amount of power used over time, and therefore, the third case study of this thesis is directed towards realizing a user-centered digital application for automated power-saving services in smart spaces. In other words, we aim to facilitate controlling various power-consuming utilities/devices (e.g., lighting system, Air Conditioning (AC) system, heating system, etc.) employed in a smart space (e.g., smart home, smart retail, smart healthcare, etc.) by implementing automated location-based digital power-saving services that detect the inhabitants' (i.e., users') presence in the smart space and turn on/off the related distributed devices based on their current location in the space. In particular, this case study focuses on controlling the lighting system as the main use case that can be extended to other use cases.

As described earlier in Section 1.2, the notion of smart spaces refers to the adoption of an IoT system whose connected objects/devices (including both sensors and actuators), which are embedded into such spaces, can communicate and share data to facilitate the fulfillment of the expected tasks and activities of these spaces' inhabitants/users. Usually, this IoT system works together with other ubiquitous computing devices to customize the experience of the prospected inhabitants/users during their journey into these spaces. An important example of these ubiquitous devices is the smart mobile devices and their integrated technologies that can play a significant role in various fields (as we already discussed their promising role in the retail industry in Chapter 2 and the healthcare industry in Chapter 3).

The potential brought by IoT systems is very promising to support effective power management in smart spaces. Traditionally, many pre-IoT efforts have been made to introduce power-saving methodologies like using motion-sensitive bulbs in the lighting control system, a limited operation time of the AC system, etc. However, adding IoT systems can enable direct energy savings for different scenarios of smart spaces. One way to realize that by implementing IoT-based real-time monitoring systems to bring optimum power consumption. The regular example is managing the HVAC (Heating, Ventilation, and Air Conditioning) system operated by electrical power, which is an essential part of any indoor space nowadays. The IoT sensors can monitor the work of motors, air compressors, boilers, fuel consumption (if required, including diesel, coal, wood, etc.), electric backup generators, other power resources including solar cells, and external batteries, etc. These collected data from the connected IoT sensors can be used and processed accordingly to optimize and reduce the total power needed to keep the HVAC system functioning normally avoiding possible power loss by the unnecessary or overlapping power consumption of different system parts.

In the pre-IoT era, the traditional power-management system will collect a sample of power usage during a time interval to monitor power consumption. Such a traditional system is good to get power-consumption data, but it does not help with alerts in case of spikes, changing usage patterns, predicting the power demand, or suggesting appropriate configuration. In a nutshell, the collected data is only a sample without real-time updates of changes. With the IoT in place, the analyses can occur on real-time data from all connected objects/devices. As a result, we can make data analysis and processing quick, easy, and more accurate, which in turn facilitates real-time alerts, predicting power demand, detecting changing usage patterns, and figuring out ways to optimize power consumption.

With the advent of several IoT-customizable utilities/devices, realizing a real-time power-management system is getting easier. For example, Philips Hue [26] introduced new lighting solutions which are IoT-ready and can be easily connected to the smart space network, and therefore, supporting customizable control of lighting system. Such IoT-ready devices can be also easily connected with smart mobile devices allowing a more flexible control and immersive UX customized for each different user accordingly. This has led to the growing usage of these mobile-controlled IoT utilities/devices which can even allow users to control them from remote locations. Consequently, users can have full real-time monitoring for all power-consuming devices in the space either locally or remotely while interacting and controlling with several devices at the same time when needed. This often results in less physical and cognitive efforts to keep track of all running devices.

Following this direction, the HCI community has investigated how the design of IoT interfaces leverages the potential to reduce the cognitive efforts of users who need to manage several devices at the same time. For example, designing an interface that is easy to control possibly by introducing multimodal interactions (e.g., visual touch interface supported with vocal interaction). Another example suggests a system that learns the habits of the users and then operates the devices automatically and as customized for the current user.

Based on the foregoing, the purpose of this research is to apply UCD approaches to design and develop a digital system that utilizes IoT devices embedded in smart spaces to provide automated power-saving services that helps users to reduce and control power consumption while navigating the space based on the current location of the navigating user (i.e., using location-based services). The proposed system will target the case study of controlling the lighting system as the main use case that can be extended to other use cases (e.g., controlling the HVAC system). The provided digital power-saving services should consider positive UX flows that space's inhabitants/users would actually adopt. The system exploits concepts from HCI allowing flexible switch between different modes of interaction when needed while leveraging the interaction with smart mobile devices and their supported multimodality. To conclude, the system investigates a promising user-centered automated power-saving services in smart spaces embedded with IoT devices, while adopting smart mobile devices that provide multimodal user interfaces and customizable experience, which in turn derives a valuable solution and added value to acquire the required service innovation in this context.

The rest of this chapter is organized as follows: Section 2 describes the research objectives of the proposed system about investigating a user-centered digital application for automated power-saving services while considering the case study of controlling the lighting system as the main use case. In

Section 3, recent relevant works are discussed. Section 4 presents the architecture of the system, introducing technical details of its software components and implementation. The final conclusion about the system's main findings, providing a critical discussion about the general applicability of the approach, and tracing possible directions of future work are discussed in Chapter 7 given the abstract context of user-oriented service digitalization and innovation.

2 Research Objectives: Investigating a User-Centered Application for Automated Power-Saving Services – Lighting Control Case Study

Before checking the recent related work of adopting UCD approaches for implementing digital automated power-saving services in different scenarios of smart spaces, together with the correlated ubiquitous computing applied and variable technologies involved, we need first to define the research objectives to achieve and the challenges to tackle in this context. In order to do so, we want to investigate in this section the case study of controlling the lighting system in a smart space (e.g., smart retail warehouse) while analyzing the system requirements to provide the related functionalities/features. After doing so, we survey the related work in order to identify, evaluate, and interpret relevant works concerning this specific topic and analyze the current limitations that need to be overcome corresponding to our case study.

2.1 Problem Fields and the Main Use Case

The big picture that the proposed system requirements want to draw is to achieve a workable digital automated power-saving solution in smart spaces focusing on lighting system control as the main use case (which can be extended to other use cases) to support the inhabitants/users while performing ongoing activities and related tasks in such spaces. Additionally, the system must consider providing a satisfying UX that alleviates overwhelming cognitive and physical demands needed to simultaneously control many different power-consuming services and devices in the space, while effectively delivering the required power-saving feature. In order to realize such a concept, we have to understand the various problem fields to be addressed, including:

- Space mapping: which handles the issue of knowing how to distribute IoT-based lighting control units within the space layout.

- Person localization: which requires to identify the appropriate (and cost-effective) technologies and technology combinations that can be used to achieve the positioning of a navigating user. The main technical challenges of this point are related to the accuracy issue. However, the required accuracy in this context can be approximated to zones instead of exact location coordinates because each lighting system unit usually covers a specific zone.

- Navigation detection: which comes after realizing the person localization technique. The main technical challenges of this point are related to the responsiveness issue by detecting correctly (i.e., effectively) and quickly (i.e., efficiently) the changes of zones of the navigating user and accordingly control the lights in the space. This is specifically important in huge spaces with many changing inhabitants (i.e., too many users that dynamically enters/leaves/changes location within the space), where you need to keep track of the active navigating users (especially in multi-user environments) within the space and possibly control many zones simultaneously.

- UX factors: which relate to positive UX practices that should be considered carefully (e.g., how fast/smooth should lighting units be turned on/off, possibly customizing the lighting color, enabling multimodal interaction with the system besides the automated control functionality while leveraging mobile devices and their integrated technologies, etc.) by observing the nature of the inhabitants' navigation pattern influenced by their usual related tasks while being in the smart space.

2.2 Functional Requirements

2.2.1 User Story

Following the defined main use case of the system, we can think of the user story as a retail employee who wants to use the lighting system of a retail warehouse to find certain items within its complex layout. To reduce power consumption during the navigation process, the proposed system will control the lighting system in a way that ensures lighting only the zone where the navigating employee is currently located. This can be realized by implementing digital power-saving services that dynamically identify the changing location of the navigating employee through utilizing the IoT sensors/devices and technologies employed in the smart retail space. This automatic dynamic localization of the navigating employee is executed using an appropriate easy-to-set-up method and cost-effective technological architecture that suits the nature of huge spaces with many changing inhabitants (i.e., too many employees that dynamically enters/leaves/changes location within the retail warehouse), where we need to keep track of several active navigating users.

A mobile device (possibly) will be used by the navigating employee during the navigation process to handle related retail tasks in the retail warehouse, which can be also used (exploiting its embedded technologies) in the localization process or alternatively enabling several UX features (e.g., customizing lighting color, enabling vocal interaction and commands, providing information about current zones, etc). The proposed system can control many zones simultaneously to support multi-user environments (e.g., when two or more employees are located in different zones, then these zones are lighted accordingly). Additionally, the system can track how many active employees are currently navigating the space, while possibly analyzing which zones are visited the most (which can be reflected in future design and maintenance of the lighting unit in that zone).

2.2.2 Basic Functionality

It should be noted that the proposed digital power-saving services can be implemented for two operation modes. The first operation mode of the system can be referred to as "anonymous navigation" where the power-saving services run independently (from any other system), automatically, and immediately once a navigating user is detected in the smart space without direct interaction from that user. This operation mode is best suited for some scenarios where storing and analyzing navigating users' identities and related navigation information (e.g., which zones have been visited by which users) is not important (or maybe not allowed for privacy reasons) for future processing and planning. However, other scenarios, like the one described in the user story of retail employees, might require "authenticated navigation" operation mode where the identity of the navigating user should be authenticated with the system so that related navigation information can be stored (possibly for security reasons and/or UX customization reasons). In this research, we will investigate the scenarios requiring the second operation mode (i.e., authenticated navigation) where usually a navigating user has an accompanying smart mobile device to handle defined tasks in the related smart space.

The basic functionality needed to realize the aforementioned user story of utilizing automated power-saving digital services (particularly for lighting control) while retail employees are navigating a retail warehouse can be divided into two main categories. First, there are the **main functionalities** that provide essential system-relevant prerequisites which enable the execution of the digital power-saving services. Second, the **additional features** that the user can exploit to achieve a more customized UX.

These two categories can be summarized as follows:

Main Functionalities:

1. **Log in to the System Using a Mobile App:** The employee starts the power-saving application on the smart mobile device to log in and possibly initiate further processes. This application can be implemented as a background process that does not need to have any visual UI (or having only a very simple one) since the relevant communicated data between the mobile application and the system are mainly related to the employee's identification, localization (possibly by utilizing Mobile's embedded technologies), or simple customized (possibly vocal) commands.

2. **Initial Detection of Employees Presence:** Once an employee is detected entering the smart retail warehouse by dedicated installed IoT objects/sensors, the digital power-saving services will start automatically and immediately to detect the identity of the navigating employee (if not already logged in to the system, and assuming authenticated navigation) by sending a notification to and communicating with the employee's mobile application. This initial presence detection will happen once the employee enters through the main door of the retail warehouse. After, once the employee decides to leave the space, the same IoT objects/sensors at the main entrance of the space will detect that and control the lighting system accordingly (i.e., keeping track of the number and zones of the remaining navigating employees in the smart space to light these zones accordingly).

3. **Continuous Detection of Employees Navigation:** After an initial detection of employees presence in the retail warehouse, other dedicated installed IoT objects/sensors will be detecting the changing location of navigating employees within the space (i.e., moving between the different zones of the space). In the context of lighting control, the concept of a zone refers to the area illuminated by a specific lighting unit.

4. **Locate Mobile Device Using BLE Beacons RSSI:** Following a cost-effective solution to provide the indoor localization feature (which is directly related to the implementation of location-based digital power-saving services) of the navigating employee within the smart retail warehouse, BLE beacons installed within this space (considering the minimum number of beacons required for a sufficient coverage) can be utilized. The smart mobile device, which is assigned to the navigating employee, can receive RSSI values of the transmitted BLE signals from these installed beacons. These RSSI values can be translated to distances from these beacons, and therefore, allowing to automatically and dynamically identify the changing location of the employee while navigating within the space (either by running the trilateration algorithm or by detecting proximity to the current closest beacon in the space). This information about the dynamic employee location will be used by the power-saving services to detect the current zone of activity and control the lighting system accordingly. Moreover, the provided accuracy using BLE signals and related RSSI values can be considered good enough to apply with the concept of a zone (i.e., approximating detected locations to a zone is a feasible solution).

5. **Support Accurate Location Detection:** This proposed functionality can be added to the system to enhance the resulted location detection accuracy by utilizing Mobile's embedded technologies like the accelerometer to double-check location changes (i.e., using the readings of the related embedded motion sensors to check if a navigating employee is currently moving or still where the latter case is interrupted as staying in the same zone). This technique is especially useful when using BLE beacons' trilateration- or proximity-based location detection due to the error-prone nature of BLE signals which can be highly fluctuating over time.

6. **Control the Lighting System:** Once an employee is detected entering/leaving a zone by the dedicated installed IoT objects/sensors, the power saving system will process this information

to control the lighting system accordingly. In other words, the power-saving services will control the related lighting units of these zones accordingly, i.e., turning off lights of the left zone while turning on lights of the entered one.

7. **Support Multi-User Environments:** Given the defined user story of retail employees who work in retail warehouses, such spaces usually have many employees navigating the space simultaneously to perform and work on various tasks. As a result, many navigating employees change zones continuously within the smart space at the same time. Therefore, the power-saving services will be responsible to dynamically control the related lighting units of these zones accordingly, i.e., turning off lights of the left zones of navigation (if no other employees are still navigating within those zones) while turning on lights of the entered ones (if not already turned on due to previous detection of navigating employees there).
8. **Extend and Update Space Map:** When a new part of the smart retail warehouse is created, the power saving system should be easily extended and updated to apply power-saving services in the new part. This requires to skillfully divide the new area into zones and install related IoT sensors and controllable lighting units accordingly considering the geometric and topological parameters of the smart space layout.
9. **Provide Additional Information about the Smart Space:** the system can track how many active employees are currently navigating the space and in which zones, while possibly analyzing those zones which are visited the most (which can be reflected in future design and maintenance of the lighting unit in that zone).

Additional Features:

1. **Control Lighting Units Smoothly:** As indicated by the corresponding main functionality of the system mentioned in point number 6, when navigating employees changes zones within the space, the left/entered zones will be turned off/on accordingly. However, this feature ensures a smooth rather than sharp transition (switching) of lights. For example, the lighting unit of the left zone can be kept switched on for a few seconds after the navigating employee leaves that zone. Afterward, it will be switched off smoothly by decreasing the lighting intensity and illumination brightness gradually over a few seconds rather than a sharp switching off.
2. **Delicate Lighting Control:** Delicate lighting control means to have zones with no navigating employees illuminated dimly rather than completely switched off in darkness (especially in closed indoor environments with no access to natural daylight). This feature will have an important psychological impact on navigating employees generally.
3. **Detecting Daylight:** The power-saving system can be enhanced by integrating light sensors into the smart space which allow to turn off all lights automatically when not needed, i.e., during daylight with enough natural light illumination in the space.
4. **Changing Lighting Color:** This feature allows a customizable selection of the lighting color in the smart space based on the current navigating user's preferences. This customization and selection of the preferred lighting color can be controlled through the power-saving mobile application.

2.2.3 Process Flow Diagram

In order to present the process flow for the main use case of the digital power-saving system controlling the lighting system in a smart space (like the smart retail warehouse scenario in our user story), the **Activity Diagram** is used as shown in Figure 45.

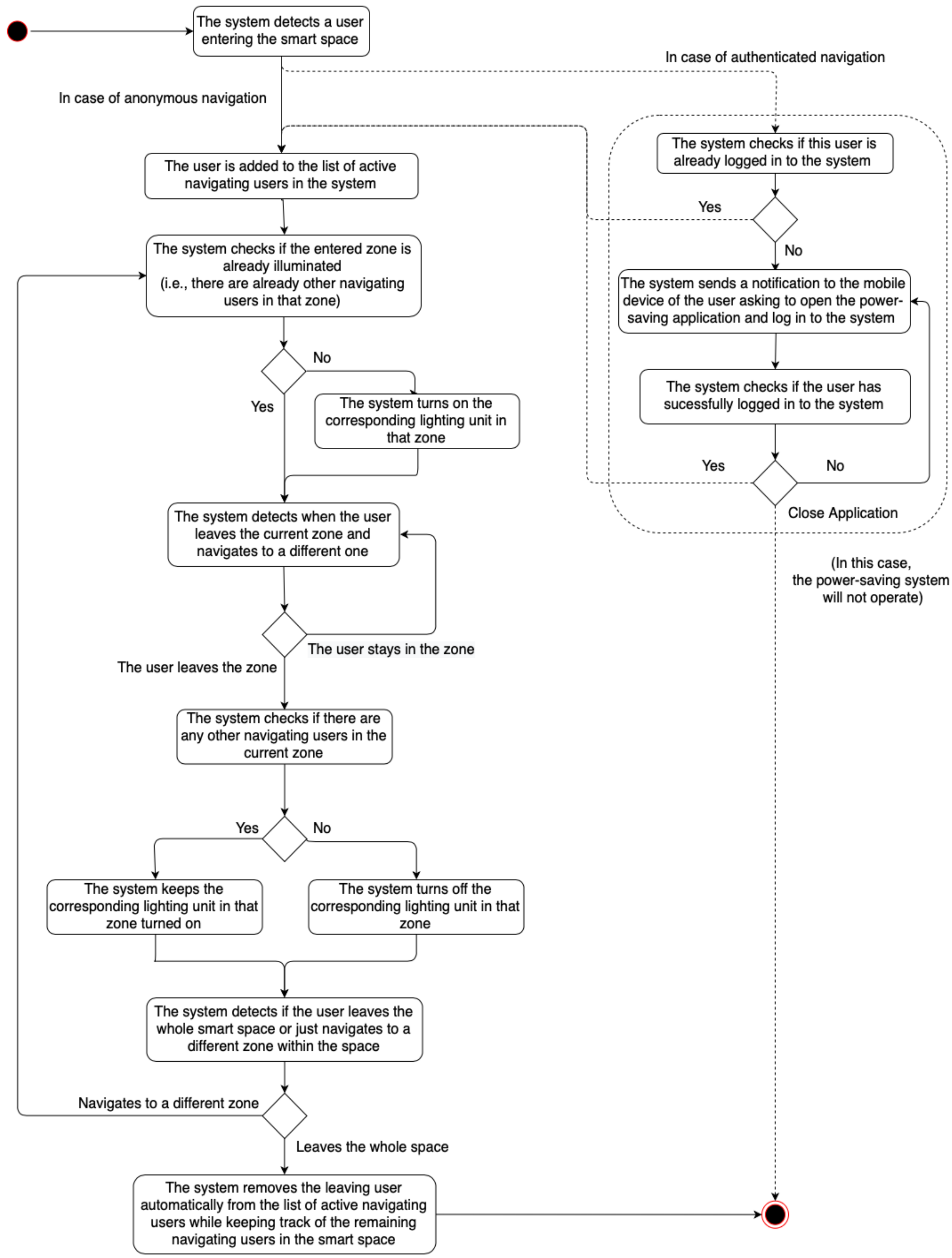


Figure 45. Activity diagram of the power-saving system.

2.3 Non-Functional Requirements

Usability:

The system should provide an immersive UX by adopting UCD approaches, starting with considering the human factors of the users in the initial requirements collection and design process until the usability testing and evaluation.

Accessibility:

The users should be able to access the different functionalities/features provided by the system whenever needed (as long as it does not violate security regulations or privacy access rules).

Availability:

The system's main functionalities including presence/location detection, dynamic real-time navigation tracking, and correct lighting unit functionality and related control should be made available to all users ensuring a fulfilling operation of the power-saving system and its provided services at any point in time during the navigation process.

Performance/Response Time:

The communication between front-end and back-end (e.g., communication between IoT sensors/objects, lighting units, and mobile application with any back-end processing at the server) must be processed in an acceptable latency (preferably maximum within few seconds considering the use case requirements like real-time controlling of the lighting system). Additionally, all installed components/devices (e.g., the lighting units) should be operating with low latencies once signaled to function.

Scalability:

Multiple users must be able to use the application at the same time. Besides, the back-end must be able to simultaneously process any amount of queries and analysis within a conventional context-specific complexity. Also, The database of the back-end has to provide enough storage capacity to store any needed data for future processing. The system should be easily configured when extending the provided digital services to new parts of the smart space.

User-Specific Functionality:

According to the user-specific functionalities, the application, upon logging into the system, should detect the identity of current users, and therefore, provide the corresponding functionalities as customized for each user.

Quality of Service:

Providing a suitable area-wide coverage range of beacon signals (when using BLE beacons) or other Installed IoT sensors/objects with adequate quality is essential to guarantee a stable and fluent navigation tracking, and therefore, a corresponding fluent operation of the digital power-saving services within the smart space. Moreover, maintaining an optimal flow of data between front-end and back-end processing to ensure that the system handles all navigating users efficiently.

Monitoring:

The users should be able to monitor all activities regarding the dynamic control of the power-consuming units (e.g., switching on/off the lighting units) in the smart space. On the other hand, system administrators should be able to track any kind of incidental issues or technical problems of all installed beacons and IoT sensors/objects and their functioning status (e.g., the remaining expected lifetime) together with the real-time operation status (if they are currently in use or idle) to maintain and optimize the functionality of the system.

Installation:

Regarding the location detection property, the BLE beacons or other IoT sensors/objects should be installed with an adequate quantity and in the best location (e.g., altitude, away from direct sunlight, not covered with other objects,etc.) and related technical parameters (e.g., installation orientation, direction of signals transmission, working temperature and humidity, etc.) in a way that ensures optimal coverage of the whole smart space layout by considering the average operational coverage of every single installed beacon or IoT sensor/object. For example, if the proposed system will exploit a proximity-based algorithm to locate the mobile devices in the case of using BLE beacons (which is reflected as users detection), at least one functioning beacon should be installed in each zone of the coverage area at any point in time. Further, regarding the use case of the lighting system control, a suitable lighting unit per zone should be installed to acquire the required illumination intensity and brightness.

Security:

All private data (e.g., user- and space-related data) has to be handled according to the defined privacy policy. These data must be encrypted and secured from unauthorized access.

Configuration:

The initial configuration of the front-end mobile application should be executed automatically without any unnecessary intervention by the end-user. Also, system administrators should have the possibility to adjust the basic settings of the system in run-time without negatively impacting the running power-saving services and system functionality.

Reliability:

In case of any incident technical failure, the system should nevertheless provide its basic functionality (e.g., the system at least allows physical lighting control in case the related digital services stopped working). The system must also be optimized to efficiently handle the limited technical capacities and specifications (e.g., memory and storage) of the utilized IoT sensors/objects, and therefore, preventing any related technical failures in advance. This calls to consider correctly which and how services are implemented on the front-end and back-end sides.

3 Related Work

In general, pre-conducted research concerning location-based services and related power-management and power-saving systems shows that different approaches use different technological means to satisfy the defined system requirements. However, while pre-IoT approaches have introduced several concepts to tackle the related power-saving challenges in lighting control context, IoT-based approaches and technologies can provide real-time monitoring with more efficiency and customized features that eventually lead to a promising UX.

3.1 Applied Technologies and Related Sensors in Location-Based Services

Realizing a promising UX of location-based power-saving services in smart spaces requires adapting variable technologies into these spaces in order to realize immersive interactivity/responsiveness with/from the power-saving system. The aim is to reliably detect the inhabitants' presence in smart spaces and know in real-time how they navigate between different locations/zones to effectively control the nearby power-consuming utilities/devices. Such technologies include electromagnetic sensors that use the electromagnetic field to automatically identify and track related tags attached to objects/users. A famous example is the RFID tags (either passive or active) that can be attached to persons and/or movable (or static) objects so that these persons/objects can be tracked by using fixed readers (special-purpose radio receivers) at different locations within the space [147]. Other technologies use electro-mechanical sensors that contain a sensitive micro switch that changes state when a mechanical actuator is displaced by the detected object/user. An example of these sensors is the inertial Micro Electro-Mechanical Sensors (MEMS) which can be combined with RFID technology to detect the changing location of navigating people as proposed by [275] to provide help in emergency situations.

In [250], a similar framework suggests using Near Field Communication (NFC) as a close-range communication technology, where NFC-enabled portable devices can be provided with software to read electronic tags, and therefore, enabling an easy data transfer for location detection while navigation just by touching installed tags spread over defined places in a building or a complex. In a different work, the pseudolite-based location detection approach is discussed [180] where pseudolite works as a signal generator that transmits GPS-like signals to nearby users to provide GPS-like navigation in an indoor environment.

Besides, magnetic sensors, which are actuated by the presence of a magnet within their sensing range, can be used for location detection purposes. In such cases, these sensors can be placed either as separate tags or embedded parts of portable devices that can be affected by the presence of a magnetic field within the indoor environment, and therefore, produce state changes as electrical signals indicating location changes during navigation. Following this direction, research of [311] exploits the uniqueness of magnetic field variations to develop a methodology to aid an Inertial Navigation System (INS) in an indoor environment. Moreover, this technology of INS is presented in many other projects to support indoor navigation experience either with magnetic sensors support (e.g., [59]) or RFID tags (e.g., [287]).

Other technologies use photoelectric sensors which typically send out a beam light and then detect a change in the amount of light received back. The three most popular photoelectric sensors are diffuse, reflective and through-beam. In diffuse sensors, the presence of an object (a navigating user in our case) in the optical field of view causes diffused reflection of the beam while the receiver detects the reflecting light. On the other hand, reflective and through-beam sensors create a beam of light and detect any opaque object that breaks the beam. The light source type (e.g., visible, infrared, LED, or laser) of these sensors will affect the sensing distance and range. For example, laser sensors can create a beam of light with a 50-meter detection range or longer. However, transparent objects, or objects with a varying surface finish, can be problematic for these photoelectric sensors. An example of using photoelectric sensors to detect moving objects is presented in [211], where Infrared sensors are used to support autonomous tracing in intelligent vehicles. Another example investigates the role of photoelectric sensors in Ambient Assisted Living (AAL) helping to track the location of elderly people in smart home context [216]. Other examples propose a combination of light sensors, inertial sensors, and WLAN signals [198, 345] to provide the required location detection in indoor environments.

Furthermore, a proposed architecture for indoor location detection systems is presented in [142] based on wearable passive sensors for measuring environmental physical conditions at both known and unknown locations in the indoor environment. Given all these examples of various technologies, there are, on the other hand, many different techniques involved to build robust indoor location-based services. One technique involves using a graph-based spatial model using geometric data to provide better visibility and route description for indoor navigation [54, 310]. Another technique deals with collected training data from wearable sensors during indoor navigation [143] to be applied for a machine learning model dedicated to enhancing context-awareness by inferring aspects of the user's state.

3.2 Power-Saving Systems for Lighting Control

Recently, many research works have been investigating several possible designs and methodologies to realize power-saving solutions that can effectively control power consuming devices of indoor environments like lighting units. In [230], the authors targeted the ineffective electrical power consumption of lighting units by proposing a dimming system that detects the daylight in the indoor environment and controls the lighting units accordingly. The system provides a solution to control both AC lighting units and DC units while taking into consideration the minimum amount of light needed in such spaces. Similarly, the work of [177] proposed an automated power-saving solution for smart home appliances to control the lighting system using motion detectors via PIR (Passive Infrared) sensors and daylight detectors via photoelectric sensors while using temperature sensors to control the fan system.

Other research proposed smart street lighting control systems to reduce power consumption in such a scenario either by active wireless communication (e.g., [336]) or by passive presence detection (e.g., [125, 91]). In the same context, other research suggested power-saving systems for both street lighting control (and related systems like automatic traffic control) leveraging clean renewable solar energy while using a distributed array of infrared sensors ([115]) or a multi-sensor system combining infrared with ultrasonic sensors (e.g., [314]) for presence detection.

Other systems were designed promoting ZigBee protocol as a cost-effective solution with low power consumption to provide lighting automation and power management solution that can be applied in various scenarios ([352, 351, 255, 323]). To that extent, the ZigBee wireless technology was also proposed to enhance solar control systems for LED lighting units [350] or combine it with GPRS for a more effective residential lighting system automation [201]. Additionally, it was introduced in other different scenarios like a central air-conditioning cold source monitoring system [58] and even a more general application of a smart home monitoring system enhanced with the voice recognition technology [158].

Another work is introduced in [269] to implement a lighting control system in highway tunnels using vehicle detection techniques and a dimming system to control the minimum required amount of light in such a context. Moreover, a power-saving system for analog street lighting control was suggested in [176] using Pulse Width Modulation (PWM) approach which allows several illumination intensity levels following the defined requirements and based on the sensor inputs. Regarding the realization of effective LED lighting systems in smart spaces, other works proposed using smart wireless sensors with smart DC-powered grid technologies [319], passive pyroelectric infrared and photoelectric daylight-detecting sensors [205], or PWM-based dimming system [89].

In the context of smart educational spaces (e.g., classrooms), an effort is made in [226] to design an effective lighting control system exploiting different approaches between switching and dimming lighting units and suggesting various related architectures to analyze related costs, power consumption, and human factors like comfort. Besides, a similar system targeted the establishment of power-saving systems in educational classrooms by detecting students' presence using PIR sensors to control the lighting system while combining them with temperature sensors to gain a more efficient solution for the fan system [325].

Towards realizing intelligent systems for power saving services, some research suggested utilizing self-adapting context-aware services by leveraging ubiquitous technologies and wireless sensor networks (e.g., [75]) while other research investigated intelligent lighting control for public places like libraries by combining collected environmental information via wireless sensor network with artificial management information (e.g., [347]). On the other hand, other systems followed the same direction while considering privacy issues by limiting the use of video-based detection techniques and instead used PIR sensors which can be more cost-effective as well [36].

Besides the required effectiveness of power-saving systems, other works targeted some non-functional requirements of such systems. For example, the work of [282] leveraged the monitoring property by introducing a warning system allowing users to monitor the status of the developed power-saving system through a dedicated LCD monitor or warning LED bulbs. Another work targeted the usability of the power-saving system by examining the users' satisfaction of using a lighting control system by considering the characteristics of space and the users' behavior patterns [76].

4 System Architecture and Implementation

After identifying the main objectives and challenges in our research topic concerning the requirements to realize a power-saving system that provides digital services to control the various power-consuming devices/utilities employed in a smart space (like a smart retail warehouse) exploiting the embedded IoT sensors/objects in such a space and leveraging mobile technologies while considering lighting system control as our main case study, and after surveying and analyzing the recent related work in the state of the art, we will proceed to present our methodology to deliver the mentioned objectives and tackle the corresponding challenges. In this sense, and complying with these requirements and the related functionalities, we employ the UCD approaches throughout the whole process from designing to evaluating the proposed prototype while trying to overcome some UX challenges and limitations in order to enhance the overall UX characteristics of the system. We will start by defining the architecture of the suggested system while discussing the implementation of all the system parts as designed for a workable running prototype.

In particular, the efficiency of the system architecture will be directly related to the accuracy and responsiveness provided by the corresponding design and implementation of the location detection functionality because the power-saving system mainly works based on the current location of the navigating users (i.e., using location-based services). Therefore, in order to explore the potential of implementing a system architecture with higher efficiency, we propose two different setups. The first setup follows Markovian processes to implement the location detection functionality using BLE beacons and leveraging mobile technologies as discussed in Section 4.1. The second setup follows non-Markovian processes to implement the location detection functionality using ultrasonic and photoelectric sensors as described in Section 4.2.

4.1 Utilizing Markovian Processes

A Markovian process is a stochastic process in which the future state does not depend on the history of the past states. Therefore, each current state is independent of the past states. Applying this concept to the location detection process (and therefore, the corresponding location-based lighting control process), the Markovian process detects the current location of the navigating user independently from the last detected location. Consequently, the current zone to be illuminated does not depend on the previous illuminated zone in which the user was navigating. In this case, the system architecture that implements a Markovian process needs to detect the changing location of the user every time as it is the first time of the user's initial presence.

In our system, BLE beacons (as signal transmitters/senders) are the IoT component of the smart space that will be used together with smart mobile devices (as signal receivers) to implement a Markovian location-based lighting control process. This is due to the way that BLE technology can be utilized to detect locations, in which the characteristics of the received signal (e.g., time, angle, strength, etc.) from a sender will be independent every time from previous times as the user navigates the space (and also due to the changing environmental factors or interference with other radio signals accidentally). These changes in received signal characteristics from different BLE beacons during navigation will be interrupted as different independently-detected locations.

Technically speaking, there are two ways to interrupt received BLE signals as distances from the transmitters, and therefore, reflected as locations within the space. The first way is to detect the proximity of a specific transmitter/beacon as described in Section 4.1.1. The second way is to detect the signals from more than one transmitter/beacon (at least three) and apply the trilateration algorithm as described in Section 4.1.2. Finally, our first architecture setup of implementing a Markovian location-based lighting control process will be using a combination of these both approaches to achieve better accuracy as described in Section 4.1.3.

The components to implement the proposed power-saving system architecture following a Markovian location-based lighting control process consist of three main parts:

- The **back-end server**, where all the main computations happen and the system's main services are provided. These services include **location service**, **lighting control service**, **daylight detection service**, and **customization service**.

  The server has a **database** that stores data about the smart space and the installed IoT objects (e.g., number of zones, number of all installed beacons and their location, etc.) that are monitored and updated by the system administrators when needed. The database can receive generated data from installed IoT objects (e.g., readings of light sensors, technical status and the expected remaining lifetime of installed units, etc.) to be processed accordingly using dedicated services (like daylight detection service). Moreover, it stores the location information of the navigating user communicated via the location service to identify the current locations of all the navigating users (i.e., in which zones they are currently located). Furthermore, it stores the navigation data (to infer more information like which zones are visited the most) and the number of navigating users in the system totally and in each zone in real-time which will be mainly used by the lighting control service to control the lighting units accordingly. Additionally, the database can store various data about users' customized preferences (like a customized color for lighting units), which will be communicated and processed via the customization service.

  In our system, the back-end server is implemented as an embedded web server of a Spring Boot web application following the MVC framework configurations. The server consists of two main parts: the first part is the system database which is implemented using MySQL database, and the second part is the available services that react to data requests/pushes by fetching/uploading data from/to the system database. These services (and others to be added later if necessary) are implemented using REST while transmitting the data using JSON format. Each service will be assigned a REST controller that will handle the related requests of each service and fetch/upload the corresponding data by communicating with the database connector. All these requests/pushes from/to the database are handled accordingly. The proposed implementation of the back-end server can be seen in Figure 46.

- The **IoT system**, which consists of all the smart connected objects embedded in the smart space, including:

  1. **BLE beacons**: which form the core component responsible (together with the technologies embedded in the smart mobile devices) of a dynamic location detection within the smart space layout, and therefore, providing the location-based power-saving services. The location changes while navigation will be communicated and updated to the back-end server (using the location service) in order to keep live tracking of all navigating users and in which zones they are currently located, and therefore, to control the lighting units accordingly.

     In our system, we used "Estimote Beacons" [6] which come with two different types. The first type is the proximity beacons which were used to implement the proximity-based location detection approach. These beacons are optimized for reliable entry and exit events (i.e., to a specifically defined proximity of the beacons) and they allow to authenticate

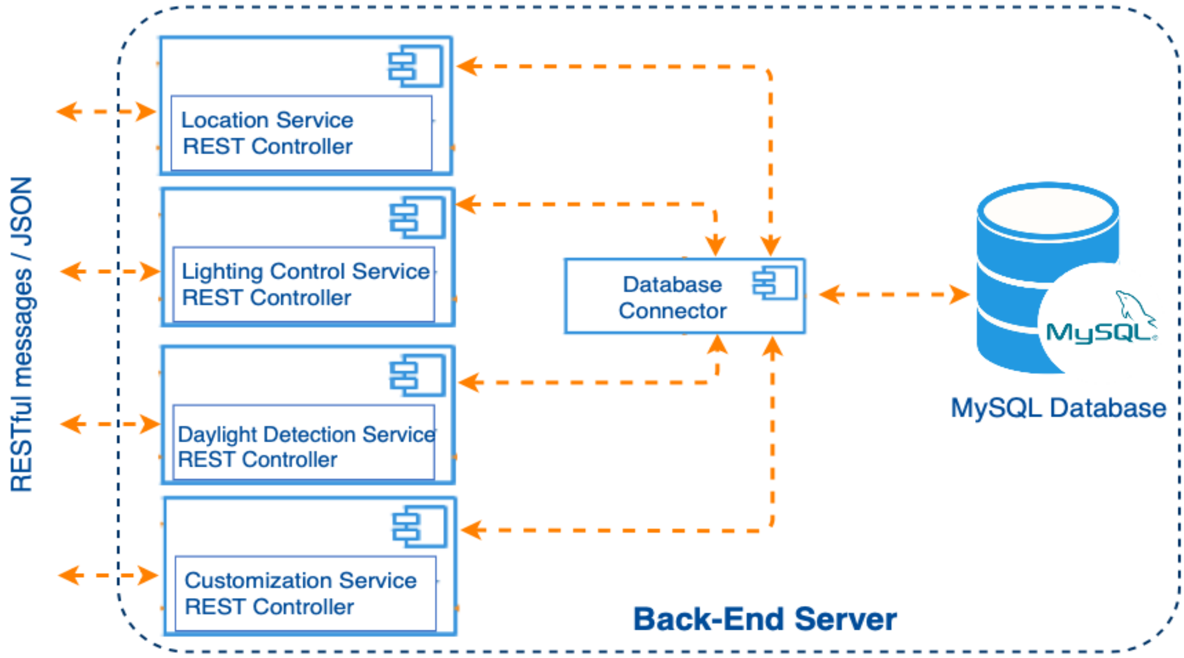


Figure 46. Back-end server implementation.

presence, send contextual notifications, display proximity-based content, or create software automation. The second type is the location beacons which were used to implement the trilateration-based location detection approach. These beacons can locate employees, provide real-time position data, collect attendance data, or deliver way-finding instructions. All relevant information about beacons' power consumption, signal strength range, and possible transmitted information are considered.

2. **Lighting units**: which are responsible to give the required light illumination in the smart space. It should be noted that a single lighting unit will be installed in each zone in the space to ensure a suitable illumination. Therefore, the properties of the installed lighting unit should be considered carefully to give adequate illumination brightness and intensity in the corresponding zone. In our system, we have used Philips Hue lights [26] and lamps as they come with various designs and shapes to suit the nature and needs of any indoor environment. The lighting units are controlled directly from the back-end server using the lighting control service based on the collected navigation information from the location service.

3. **Other IoT sensors**: which collects data about the environment helping to implement a more effective power saving solution. For example, utilizing light sensors that detect if there is enough ambient light from natural daylight and communicating this information via HTTP to the back-end server using daylight detection service in order to control all the lighting units accordingly. In our system, we have used UUGear light sensor module [33], which can be easily installed and programmed for a specific light threshold.

- The **front-end mobile application**, which utilizes the integrated technologies (mainly the Bluetooth module which receives BLE signals from transmitting beacons) to implement a dynamic location detection within the smart space layout, and therefore, providing the location-based power-saving services. The mobile application communicates with the back-end server via HTTP in order to run a service. For example, the mobile application sends the results of location computation by proximity- or trilateration-based algorithm to the back-end server to update it about the navigation information in real-time. On the other hand, the mobile application can call the customization service which, for example, can allow the user to change the lighting unit color.

Consequently, the back-end server will run the lighting control service to correspondingly control the lighting units to use the selected color as customized by the user. Both front-end and back-end services should be implemented carefully considering the data flow requirements, and the possible front-end mobile device specifications and technical limitations. This will ensure the smooth functioning of the front-end mobile application, and consequently, the efficiency of the whole provided power-saving system.

The proposed system provides a platform-independent front-end solution that is implemented using the open-source Ionic framework [16]. This free-access framework built on top of Apache Cordova [2] allows hybrid mobile application development which can be rendered into a web layer application that can run regardless the underlying native layer of the used smart mobile device assigned to the navigating user (very similar to the implementation of the front-end mobile application of the localization service in the first case study of this thesis in Chapter 2). Additionally, Cordova Plugin iBeacon [3, 4] is used to communicate with the installed Estimote Beacons.

4.1.1 Proximity Based

In the proximity-based approach, transmitted BLE signals from installed beacons in the smart space will be detected and received by the smart mobile device of the navigating user. The front-end mobile application will then sort the RSSI values of these received signals from all detected beacons in descending order, where the beacon with the highest received RSSI value reflects the current closest beacon. Consequently, this information will be communicated to the back-end server (via the location service), and therefore, the system can identify that beacon having the highest received RSSI value and the corresponding zone where it is installed (because, as indicated earlier, there is at least one beacon installed per zone). Afterward, the system (via lighting control service) will control the lighting units accordingly. The functionality of this approach is shown in Figure 47a.

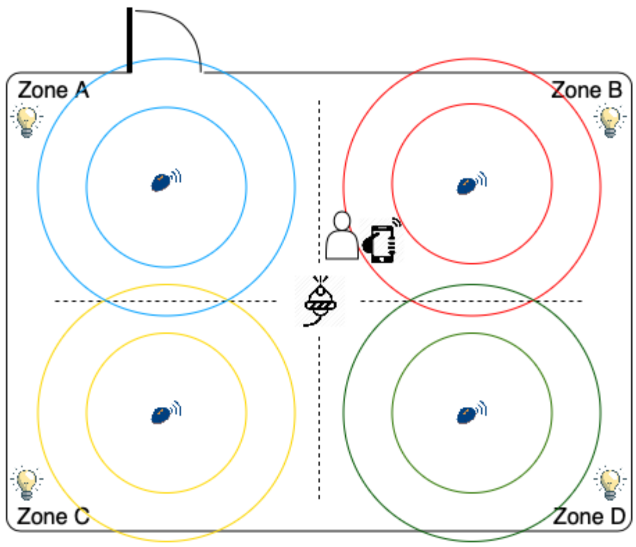
4.1.2 Trilateration Based

In the trilateration-based approach, transmitted BLE signals from installed beacons in the smart space will be detected and received (similarly to the proximity-based approach) by the smart mobile device of the navigating user. However, after the front-end mobile application will sort the received RSSI values in descending order and select the group of beacons (at least three) with the highest received RSSI values (i.e., current closest beacons), it will use the mathematical geometry of the space by knowing exactly where these closest beacons are located and the distance to each of them (as interrupted by their received signals) then applying the trilateration algorithm to calculate the current related coordinates within the space. Consequently, this information will be communicated to the back-end server (via the location service), and therefore, the system can identify in which zone the user is currently navigating (based on the current calculated location coordinates). Afterward, the system (via lighting control service) will control the lighting units accordingly.

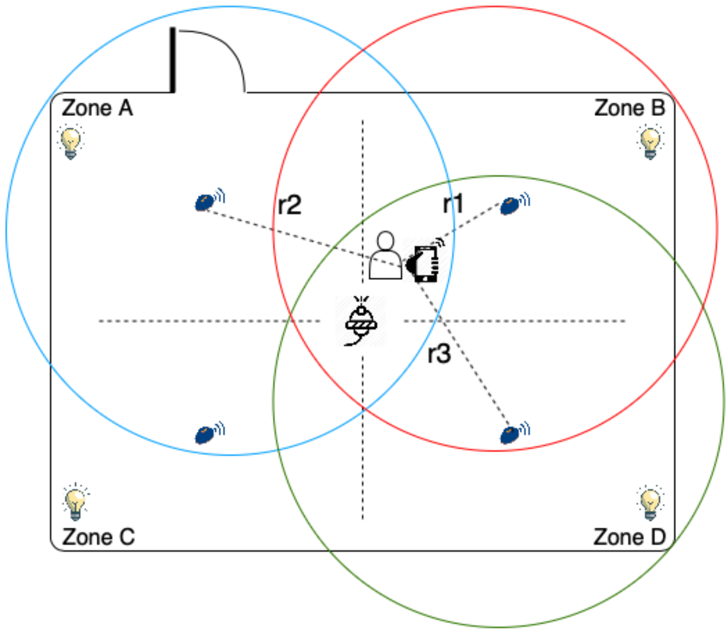
This approach is very similar to the one used to implement the localization service in the first case study of this thesis in Chapter 2. In particular, more details about calculating locations using the trilateration approach are discussed in Section 4.3.1. The functionality of this approach is shown in Figure 47b.

4.1.3 Setup 1: Combination of both

Our first architecture setup to implement the proposed power-saving system following a Markovian location-based lighting control process will be using a combination of both proximity and trilateration



(a) Proximity-based approach.



(b) Trilateration-based approach.

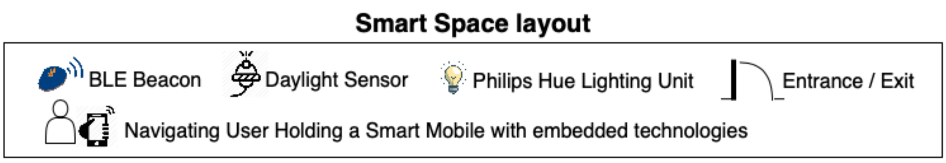


Figure 47. The two different approaches to implement a Markovian location-based lighting control process in a smart space layout. The smart space has a daylight sensor at the center and is divided virtually into four zones: A, B, C, and D. Each zone has one installed Philips Hue lighting unit and a central BLE beacon unit. The first proposed architecture setup of the power-saving system uses a combination of both approaches to achieve better accuracy.

approaches to achieve better accuracy. First, the system will run the trilateration algorithm to detect current coordinates of the navigating user (based on the predefined coordinates of the installed beacons) within the space and map it to the corresponding zone. Afterward, the system verifies if the detected zone is the correct one by running the proximity algorithm to detect the closest beacon (i.e., the one with the highest received RSSI value) in the proximity and its corresponding zone. If we have a match of both detected zones from both techniques, then we turn on the corresponding lighting unit of that zone.

In order to achieve better accuracy of the system, the embedded technologies of the smart mobile device, like the motion sensors, can be used to detect if the user is remaining within the same zone or moving and navigating to different zones. This is particularly helpful when using BLE beacons' trilateration- or proximity-based location detection to overcome the error-prone nature of BLE signals which can be highly fluctuating over time due to the changing environmental factors or accidental interference with other radio signals. On the other hand, the system can automatically detect if there is enough ambient daylight in the smart space (via the light sensors) and control the lighting system accordingly for a more effective power-saving solution.

4.2 Utilizing Non-Markovian Processes

A non-Markovian process is a stochastic process in which each future state depends on the past states. Applying this concept to the location detection process (and therefore, the corresponding location-based lighting control process), the non-Markovian process detects the current location of the navigating user depending on the last detected location. Consequently, the current zone to be illuminated depends on the previous illuminated zone in which the user was navigating. In this case, the system architecture that implements a non-Markovian process should keep tracking of the previous detected location/zone of all navigating users after detecting their initial presence.

In our system, object detection sensors are the IoT component of the smart space that will be used to implement a non-Markovian location-based lighting control process. This is due to the way that these sensors can be utilized to detect changing locations/zones of the navigating users, in which the sensors will be installed at the virtual boundaries between adjacent zones and their signals will detect users when they are passing these boundaries (i.e., changing zones). Therefore, the lighting control process will be dependent every time on both the last detected zone of navigation and the next direction/zone of navigation.

Technically speaking, two sensors were chosen to detect users when they move between adjacent zones within the space. The first one is the ultrasonic sensor as described in Section 4.2.1. The second one is the LIDAR photoelectric sensor as described in Section 4.2.2. Finally, our second architecture setup of implementing a non-Markovian location-based lighting control process will be using a combination of these both sensors to achieve better accuracy as described in Section 4.2.3.

The components to implement the proposed power-saving system architecture following a non-Markovian location-based lighting control process consist of three main parts:

- The **back-end server**, which has the same architecture and implementation as discussed in Section 4.1 and shown in Figure 46. However, it should be noted that the logic of some services is implemented differently due to the different IoT components used. For example, the location service will be implemented based on the object detection sensors like ultrasonic and photoelectric instead of BLE beacons. Other services including lighting control service and daylight detection service are the same.

  It should be also noted that the database will store the related data of the object detection sensors instead of the BLE beacons (e.g., between which adjacent zones each sensor is installed). Other data related to the other installed IoT components including the lighting units and daylight sensors are stored in the same way. Additionally, the data about space (e.g., number of zones, number of active users per zone, which zones are visited the most, etc.) are stored similarly. Moreover, the data about users and their customized preferences (if any) are stored equivalently.

- The **IoT system**, which consists of all the smart connected objects embedded in the smart space, including:

  1. **Ultrasonic Sensors**: which form the first alternative option to implement a dynamic location detection within the smart space layout, and therefore, providing the location-based power-saving services. These sensors typically transmit a short burst of ultrasonic sound toward a target (a navigating user in our case), which reflects the sound back to the sensor. The sound wave is well reflected by almost all dense materials (metal, wood, plastic, glass, liquid, etc.) and is not affected by color, transparent or shiny objects.

     Therefore, after a navigating user is detected passing by any of these sensors, this detection will be interrupted as changing locations/zones (assuming the sensors are installed at the boundaries between adjacent zones). These location changes while navigation will be communicated and updated to the back-end server (using the location service) in order to keep live tracking of all navigating users and in which zones they are currently located, and therefore, to control the lighting units accordingly.

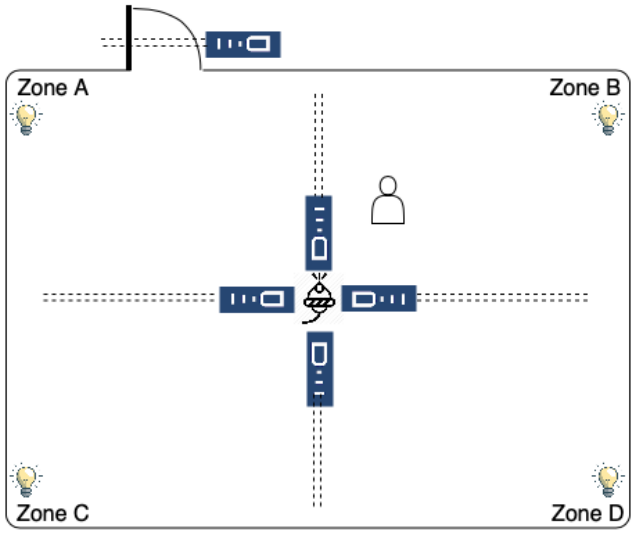
     In our system, we used "Ultrasonic Distance Sensor HY-SRF05" [32] which can detect objects (i.e., navigating users) within a range up to 4.5 meters. All relevant information about the sensors' power consumption, operating temperature range, and angle of detection are considered. It should be noted that the selection of the ultrasonic sensor and related detection range depends on the layout geometry of the smart space, i.e., how it is divided into zones and the length of the virtual boundaries between adjacent zones along which the sensors need to detect navigating users.

  2. **LIDAR Photoelectric Sensors**: which form the second alternative option to implement a dynamic location detection within the smart space layout, and therefore, providing the location-based power-saving services. These sensors typically send out a beam light and then detect a change in the amount of light received back. The three most popular sensors are diffuse, reflective and through-beam. Additionally, the light source type (e.g., visible, infrared, LED, or laser) of a sensor will affect the sensing distance and range.

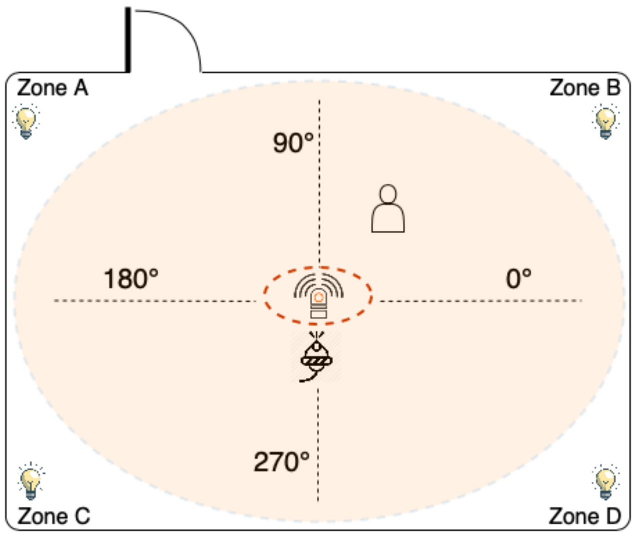
     In our system, we used "YDLIDAR X4 Lidar 360-degree Laser Range Scanner" [27] which can detect objects (i.e., navigating users) within a range up to 10 meters in all directions (i.e., 360-degree detection). In this case, the detection area will be a circle, where the sensor will be placed at the center of the circle and the boundaries between adjacent zones can be defined as radiuses virtually drawn at specific angles. Therefore, the sensor can scan the circle area with a specific frequency (depending on the required responsiveness) to detect if users have changed their locations from the previous scan.

     If the detected location changes are within the same zone (as defined between specific angles) nothing will change and the lighting system will keep operating in the same state. Otherwise, if a navigating user is detected passing between the virtual boundaries (i.e., defined angles) of different zones, the system will control the lighting system accordingly. These location changes while navigation will be communicated and updated to the back-end server (using the location service) in order to keep live tracking of all navigating users and in which zones they are currently located, and therefore, to control the lighting units accordingly.

     All relevant information about the sensors' power consumption, operating temperature range, and various possible scanning frequency are considered. It should be noted that the selection of the LIDAR sensor and related detection range depends on the layout geometry of the smart space, i.e., how it is divided into zones and the length of the virtual boundaries between adjacent zones along which the sensors need to detect navigating users.



(a) Ultrasonic-based approach.



(b) LIDAR-based approach.

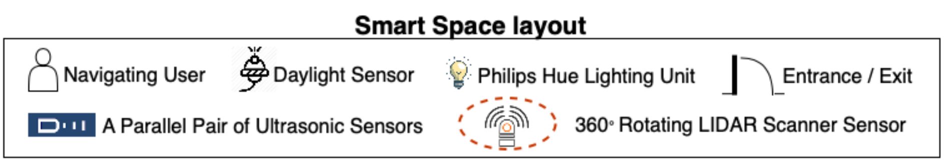


Figure 48. The two different approaches to implement a non-Markovian location-based lighting control process in a smart space layout. The smart space has a daylight sensor at the center and is divided virtually into four zones: A, B, C, and D. Each zone has one installed Philips Hue lighting unit and is separated by virtual boundaries from other zones. In the case of using ultrasonic sensors, the boundaries are defined by the line-of-sight detection of each sensor. In the case of using LIDAR sensors, the boundaries are defined at a specific angle of detection. The second proposed architecture setup of the power-saving system uses a combination of both approaches to achieve better accuracy.

3. **Lighting units**: which has the same Philips Hue units as discussed in Section 4.1.
4. **Other IoT sensors**: which has the same UUGear light sensor module for daylight detection as discussed in Section 4.1.

- The **front-end mobile application**, in this architecture, the mobile application does not provide any functionality regarding the location detection, and therefore, can not be considered important (especially in anonymous navigation mode) compared to its main role in the previous architecture setup discussed in Section 4.1. However, the customization service implementation depends on using a mobile device during navigation as it provides the interface to communicate with the system using the front-end mobile application.

4.2.1 Using Ultrasonic Sensors

In this approach, the location detection of navigating users is performed using only ultrasonic sensors. When a navigating user is detected crossing the line-of-sight range of any of these sensors, this detection will be interrupted as changing zones (assuming the sensors are installed at the boundaries between adjacent zones). The sensors will be also installed at the entry/exit points of the smart space to detect when a user enters/leaves the space and the corresponding entry/exit zone. To detect the direction of navigation (i.e., which zone was entered/left), each boundary between two adjacent zones will be controlled by a pair of ultrasonic sensors. Hence, the direction of navigation can be determined by knowing which sensor detects the user first.

Finally, this information about users' zone changes while navigation will be communicated to the back-end server (via the location service), and therefore, the system can keep a live tracking of all navigating users and in which zones they are currently located. Afterward, the system (via lighting control service) will control the lighting units accordingly. The functionality of this approach is shown in Figure 48a.

4.2.2 Using LIDAR Photoelectric Sensors

In this approach, the location detection of navigating users is performed using only LIDAR Photoelectric Sensors. This sensor, which is placed at the center of the circular detection area with a predefined radius of detection range, will be performing a periodic 360-degree scanning with a specific frequency (i.e., specific number of scans per second) to detect any changes in users locations over time. If the system detects location changes within the same zone (i.e., between specific angles that define a zone), then nothing will change and the lighting system will keep operating in the same state. Otherwise, if a navigating user is detected passing between the virtual boundaries (i.e., defined angles) of different zones, the system will control the lighting system accordingly.

Consequently, this information about users' zone changes while navigation will be communicated to the back-end server (via the location service), and therefore, the system can keep a live tracking of all navigating users and in which zones they are currently located. Afterward, the system (via lighting control service) will control the lighting units accordingly. The functionality of this approach is shown in Figure 48b.

4.2.3 Setup 2: Combination of both

Our second architecture setup to implement the proposed power-saving system following a non-Markovian location-based lighting control process will be using a combination of both ultrasonic and LIDAR photoelectric sensors to achieve better accuracy. Initially, the ultrasonic sensors will detect when a user crosses any boundary between two adjacent zones. Besides, the system will use the LIDAR sensor scanning to verify the related zone changes of detected navigating users. When the system confirms a zone change from both sensors, then it will control the corresponding lighting units of these zones accordingly (i.e., by turning on/off the entered/left zone).

In case the navigating user has a mobile device running the front-end mobile application (and therefore, navigating the smart space in authenticated navigation mode), the embedded technologies of the smart mobile device, like the motion sensors, can be used to detect if the user is remaining in place or moving and navigating around. This can help to save the power of running the other sensors all the time, especially when the user stays for a considerable amount of time at the same location without moving. On the other hand, the system can automatically detect if there is enough ambient daylight in the smart space (via the light sensors) and control the lighting system accordingly for a more effective power-saving solution.

Chapter 5

Evaluating Humans Collaboration Attitude towards Service Robots in Symbiotic Autonomy Settings

1 Introduction

At a growing pace, robots are being introduced in human-populated environments, such as healthcare, assistance in indoor public and private environments, and entertainment. In these social scenarios, robots are expected to cooperate with humans, and therefore, to interact with them by showing acceptable behaviors and capabilities. We aim at enabling more natural social behaviors and allow service robots to enter our everyday environments more naturally. Subsequently, this will guide towards a user-centered operation of RaaS units, which in turn participates in the required innovation of service digitalization.

Given the current state of technology, robots autonomy significantly varies depending on the environment, on the task to be executed and on the robot platform itself. For instance, many types of robots are constrained by their embodiment, as in the case of low-cost mobile robots. As long as they do not feature a manipulator, robots will not be able to accomplish tasks such as grasping an object, open a door or simply push a button. To overcome these limitations, robots may ask for help, and accordingly, humans should be willing to help robots in achieving their tasks. In literature, this mutual dependency has been introduced as Symbiotic Autonomy [284] or Symbiotic Robotics [99], where robots perform service tasks for humans, while humans help them to achieve their goals. Generally, in Human–Robot Interaction (HRI) studies research addresses the case of humans asking for help. In such a scenario, interactions are triggered by humans in order to take advantage of robots' services. Instead, the evaluation of how the robot should behave to successfully receive humans' help, and in which context it is better to ask for it, represents a novel scenario to be investigated.

The aim of our work is to discover and characterize possibly influencing factors of human attitude in helping a robot to accomplish its tasks. Hence, we hypothesize that human attitude has not a constant value, but depends on identifiable factors imposed by human physiology and by the context in which they are operating. In particular, we are interested in factors that can be actually observed and detected through state-of-the-art robotic perception. This is a key point in our working hypotheses as we want the robot to eventually interact with people and estimate their Collaboration Attitude by solely relying upon its sensors. To this end, we evaluate these influencing factors over a population of users selected in our department.

This research part of the thesis reports and expands the results of a user study presented in [276], focused on the evaluation of the Collaboration Attitude, when specific factors such as "Proxemics" (i.e., relative pose of the interactive partners), "Gender" of the participants and "Context" (i.e., operational environment of the interaction) are not constant. The data collected in this first experiment revealed that while Proxemics settings and Gender play a key role in influencing the Collaboration Attitude of participants, we can not make any obvious conclusion on the influence of the Context, which is characterized by the location where the interaction takes place. Hence, through a second user study, we decided to better investigate the notion of "Activity" in which the human is involved, when the interaction is triggered by the robot. To this end, rather than considering the context in which the interaction is carried out, we focused on studying the type of activity in which the user is involved, when (s)he is interrupted. The findings of this latter study help us in generating a model of interaction that defines: (i) whether different activities may influence the Collaboration Attitude, and (ii) the values maximizing it.

The remainder of this chapter is organized as follows: Section 2 discusses the related work, while Section 3 provides a formalization of Collaboration Attitude and defines our working hypotheses. Section 4 presents our system and the setup of the experiments. In Section 5.1, we report the experimental results of the first user study, while in Section 5.2 the empirical evidence of the second user study are presented. In Section 6, the results are discussed and, finally, in Chapter 7 we draw some conclusions about the system's main findings, providing a critical discussion about the general applicability of the approach, and tracing possible directions of future work given the abstract context of user-oriented service digitalization and innovation.

2 Related Work

Symbiotic Autonomy [284], or Symbiotic Robotics [99], describes a new paradigm in the collaboration between humans and robots, which is defined as a symbiosis between human and robot to enable a better coexistence of both. Several works in literature investigated how to enable such a cooperation among humans and robots. For instance, in [133] the authors study how to adapt robot behaviors to human preferences, while in [243] such a problem is faced by analyzing human responses to a robot offering domestic services. Differently from these works, where Collaboration Attitude is kept stable during the experiments, we assume that the Collaboration Attitude has not a constant value and depends on many factors such as general user attitudes, human comfort and also on the type of activity that involves the user at the moment of the interaction.

Several user studies try to formalize a baseline to establish robot behaviors that guarantee a proper level of comfort during human–robot interactions. For example, in [186, 239] the authors find the best setting for enabling socially acceptable behaviors in handing-over objects and in properly gazing at the interactive partner. In [318], a user study is conducted to compare human–robot interactions, that involve users with a different personality, gender, height, and pet ownership. Similarly, in [235] the robot autonomously estimates the comfort-level of the operators, by comparing gaze orientation and physical distances in order to adapt its behaviors to specific participants; [339] represent the interactions as fuzzy-rules that can be updated online by an external operator. However, none of the aforementioned studies assumes the perspective of the robot taking the initiative toward the user. In fact, while in these studies the focus is to shape the robot behavior in response to a human request, here we enable the robot to interrupt users in order to evaluate which are the behavioral and contextual features maximizing their Collaboration Attitude. More related to our study, Rosenthal [285] and [284] present a study about the behavior of a robot that needs help in the context of Symbiotic Autonomy. Even though their robot is also allowed to query humans, they do not analyze factors that may influence humans attitude to collaborate. Thus, no quantitative formalization and evaluation of the Collaboration Attitude are provided.

More recently, in [50, 349] the authors evaluate whether and when a robot should take initiative to support a user in an assembling task. Differently from our assumption of selfless help to support the robot, in this work the user has full interest in collaboration and interaction. In [166] the authors propose an interesting study on affordance-based altruistic behaviors for collaboration. Even in this case, altruistic behaviors are exploited to support the user in its task. However, this work points at promising factors to consider in order to better investigate collaboration attitude by relying on the sensorimotor mechanism and object affordance.

Summarizing, most of the cited works aim at determining the "best configuration" for a robot, that has to carry out a task assigned by a user. Under this perspective, the goal is to minimize the level of discomfort that can be caused. The main difference between our work and those reported in the literature lies in the premises of the task, that is here characterized by a robot asking for help and a user that is supposed to support it. In fact, we aim at evaluating the Collaboration Attitude of the subjects (proactive behavior), rather than their preferences during a Human–Robot Interaction (passive behavior)—as in [317]. Hence, in this different perspective, we want to both minimize the level to discomfort and determine the best setting for robots that approach humans and ask for help. To the best of our knowledge, our research is the first to present an analysis of the Collaboration Attitude and that studies its enabling factors with the goal to allow for more natural human–robot interactions.

3 Research Objectives: Investigating the Concept of Collaboration Attitude

In order to study the collaborative inclination of humans toward robots, we need a quantitative measure that captures the concept of Collaboration Attitude. To this end, the Collaboration Attitude has been modeled as a N-point Likert scale as follows:

Definition 1 (Collaboration Attitude) The Collaboration Attitude measures the attitude of humans toward the requests for help of the robot in a Symbiotic Autonomy framework. Formally, it is quantified according to metrics defined on a scale of N + 1 points, where N is the number of tasks that the human is requested to accomplish. Precisely, the Collaboration Attitude assumes values in [0, . . . , N], where 0 represents the lowest level of collaboration, i.e., the human is not willing to help at all, while N represents the highest one, i.e., the human is willing to help the robot in all the tasks.

The concept of Collaboration Attitude is already introduced in [276], that provides also a first user study analyzing possible influencing factors. The results collected in the study confirm the role played by factors already known to influence the interaction with the robot under a passive behavior. However, the statistical analysis did not show a significant relationship with the environmental context in which the interaction takes place. To this end, we planned a new user study aiming at validating our intuition that the situation where the interaction takes place makes a difference. In this new user study, we focused on the activity carried out by the user, characterized as sitting and standing. This is a significant simplification which is motivated by our aim to consider only features that can actually be implemented given the current state of robotic perception. Below we formalize the working hypotheses of the two user studies.

3.1 User Study 1: Proxemics, Gender and Context

In this user study, the robot asks people for help in different Contexts (namely, Relaxing and Working), with different Proxemics settings (namely, Intimate, Personal and Social).

The analysis of such factors generates a model of interaction that defines: (i) whether they actually influence the Collaboration Attitude, and (ii) the values that maximize it. Eventually, such a model may be used to shape the proper social behavior of robots asking for help, depending on the current working context. Operationally, we are interested in analyzing the following four hypotheses.

Hypothesis 1 Collaboration Attitude is subject to different Proxemics settings

It is well known that Proxemics has a key role in both human-human and human–robot interaction. Therefore, experiments aim at highlighting the importance of respecting the personal space in social interactions, even in the case where the interactive partner is a robot. Specifically, we want to estimate whether different settings of Proxemics might vary the Collaboration Attitude that the human shows, ranging from an intimate distance to a social one.

Hypothesis 2 Collaboration Attitude is subject to the gender of the human

Humans' physical and social characteristics affect how they behave in different situations. Gender is one of the major features to be considered. Such a factor is usually considered in HRI studies, as males and females show different responses to equal stimuli.

Hypothesis 3 Collaboration Attitude is subject to different Contexts

The environmental context of the interaction plays a central part in social interactions. People behave differently, depending on where they are and the contexts they are in. Consequently, a robot needs to consider these social elements.

3.2 User Study 2: Human Activity

In this second user study, a robot interrupts people in order to ask for help, approaching people that are involved in different activities. Operationally, we are interested in analyzing the following hypothesis.

Hypothesis 4 Collaboration Attitude is subject to different human activities

When the robot asks for help, the human activity affects the level of collaboration. Specifically, we consider users to be in a Standing activity, if they stand at a location or are walking—for example, whenever they are going to a meeting or attending a class, or equivalently if they are having a coffee. We consider users to be in the Sitting activity, instead, if they are sitting in the open areas, for example taking a break, having lunch or studying.

4 Methodology

The degree of Collaboration Attitude in changes to the dependent factors has been analyzed through two subsequent user studies. However, the subjects selection policy, apparatus, procedure and questionnaire are essentially the same. In fact, for each user study, we executed different runs of the same experiment by interrupting users in different activities and asking them to confirm the activity in order to discard outliers. This section introduces our subject population, the tools that supported execution of the user study, the procedure of the experiment and the questionnaire.

4.1 Study Subjects

All the experiments have been conducted in a department of Sapienza University of Rome. In such an environment, the users have been randomly selected from a set of students with homogeneous characteristics, all of them between 20 and 30 years old. We collected 78 and 206 participants, for the User Study 1 and 2, respectively, completed in a "between group" design, so that every user participated only once and the data collected is not biased by repetitions of the experiments by the same user. Participants have not been compensated, nor have they provided any consensus for

Figure 49. Modified Turtlebot robot. The platform deployed is higher than the standard version, and features a tablet which is used to carry out interactions with users.

taking part in the experiment. This choice has been necessary to prevent possible bias in the results of the experiments.

4.2 Study Apparatus

In both user studies, the deployed robot is the same modified version of the Turtlebot Robot (see Figure 49). While the base remains unaltered, the structure on top of it has been customized, in order to make the robot taller with respect to the standard version. In fact, with a tablet on top as an interface for spoken interactions, it weighs approximately 7 kg and it is 98 cm high. We allow users to have short-term dialogues with the robot, to support the estimation of the attitude of the human to help the robot in performing its tasks. Our short-term dialogue system is composed of two main modules: (i) an Automatic Speech Recognizer (ASR), that processes the acoustic signal of the users' speech and generates a set of possible transcriptions; (ii) a Dialogue Manager (DM) that manages the dialogic interaction. The ASR module has been realized through the Google Speech APIs, available within the Android environment, in an ad-hoc mobile application. The application is also in charge of managing the questionnaire presented to the user at the end of the interaction, through a touch-based Graphical User Interface. The dialogue flow is managed through an Artificial Intelligence Markup Language (AIML) Knowledge Base.

4.3 Study Procedure

We conducted our studies both in closed and open areas of a department in our university, where the heterogeneity of both environment and population gives the opportunity to collect data for each value of the considered factors. The whole experiment is conducted in a Wizard-of-Oz fashion [278] and includes a predefined set of four phases, namely Approach, Dialogue, Questionnaire and Homing. Meaning, all of the robot's behaviors are result of remote control by an expert not visible to the participant. During the Approach phase, the robot approaches the user that is not aware of being involved in the study until the questionnaire is displayed. The user is randomly selected by the operator is controlling the robot. Given the purpose of the study, only this phase slightly differs

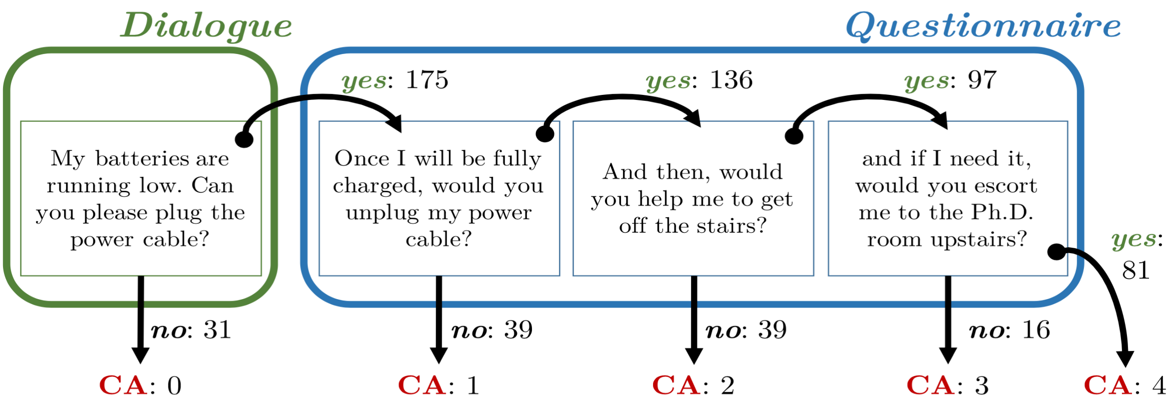


Figure 50. Collaboration attitude estimation through questionnaire.

depending on the Proxemics factor and its values. In fact, once the expert chooses the next user, the robot notifies it is seeking for help. The robot asks the participant to keep his/her position. Afterwards, the robot approaches the user within one of the Proxemics settings. In particular, the robot approaches all the participants within the "Personal" Proxemics setting. We did not vary the orientation of the robot during the experiments, as other works [186, 321] focused on the relative orientation of the robot with respect to the user. In the case of the sitting activity, the robot goes towards the user by respecting the same social distance [150, 321], while in the standing setting, it intercepts the human which is passing by or standing still. If the approach phase fails, we can not assess whether the participant would have been willing to help the robot or not. Hence, we do not take into account these cases in the final data. After that the user attention is gained, the Dialogue phase is triggered and the robot asks to be helped in a particular task. After this short interaction, the robot displays the Questionnaire on the table aiming at completing the evaluation of CA and collecting users' information. It is worth emphasizing that during the user study, we collected different information about the participants such as acquaintance toward robotics and comfort in talking English—the whole experiment is executed in English. However, we report only the factors that are actually detectable and observable through robot perception (e.g., gender, height, posture).

Once the questionnaire has been completely filled in, the Homing phase is executed, where the robot thanks the user and is guided toward its original position. The user is then free to walk away: in fact, we do not ask participants to actually perform the robot requests, as we are only interested in their willingness to do them.

4.4 Study Questionnaire

We collected data by asking the user to fill in a questionnaire that the robot displays on the tablet. We divided the questionnaire into two sections aiming at (i) quantifying the Collaboration Attitude, and (ii) collecting information about the user. Specifically, we characterize users by gathering information about gender and acquaintance toward robotics.

The Collaboration Attitude is mapped into a 5-point scale, measuring the number of positive responses of the participants to the robot requests, according to Definition 1. Hence, if we consider also the initial request (in the Dialogue phase), this variable takes values in $0, \ldots, 4$, where 0 is the case where the human is not willing to help the robot in any task. Conversely, the Collaboration Attitude is 4 when the user is willing to help the robot in all the tasks.

Figure 50 shows the requests posed to the participants. While the first request is part of the dialogic interaction, the remaining three are both uttered by the robot and displayed as part of the questionnaire. The number on each edge refers to the occurrences of a particular answer of the second user study, i.e., yes or no. In particular, arcs labeled with no represent users giving up in

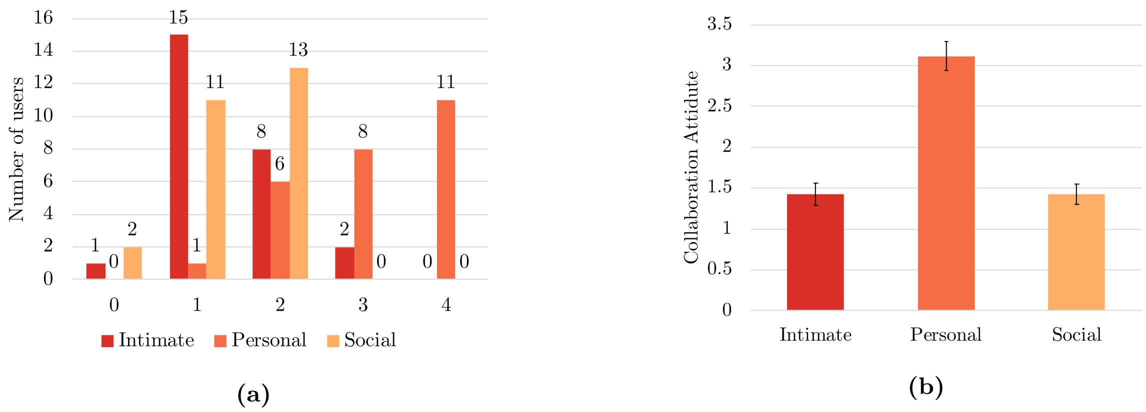


Figure 51. Collaboration Attitude analysis of the first user study with respect to the "Proxemics" factor. (a) Users' Collaboration Attitude levels divided with respect to the "Proxemics" factor; (b) Collaboration Attitude means and standard errors with respect to the "Proxemics" factor.

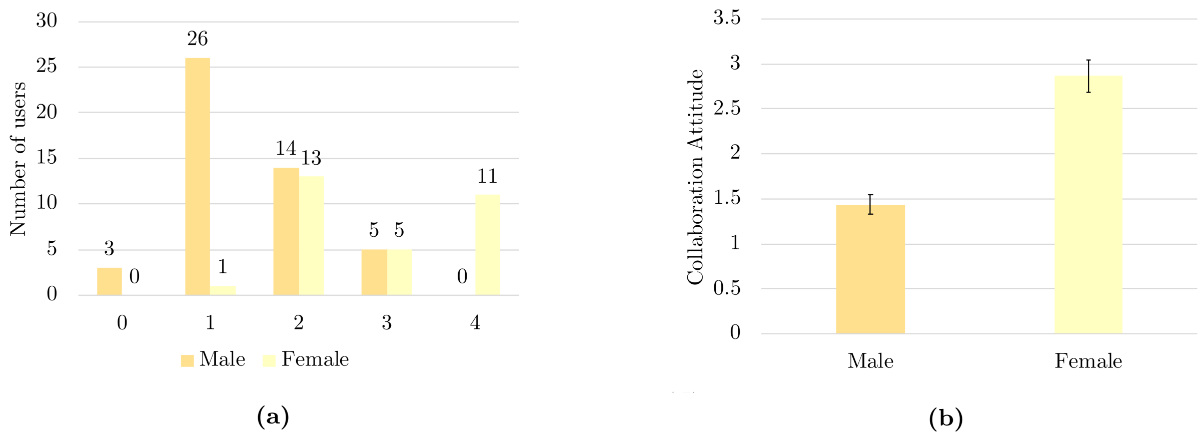


Figure 52. Collaboration Attitude analysis of the first user study with respect to the "Gender" factor. (a) Users' Collaboration Attitude levels divided with respect to the "Gender" factor; (b) Collaboration Attitude means and standard errors with respect to the "Gender" factor.

helping the robot at a particular CA request, while arcs labeled with yes count users that advanced through the different questions. For instance, in the second user study, the 31 users neglecting the initial request achieved a CA of 0, while the 81 users that satisfied all the robot requests obtained a CA score of 4. As one might expect, the engagement decreases as the requests become more and more demanding. In fact, at each question (except for the fourth request) 36 users on average abandoned the robot.

5 Experimental Results

5.1 User Study 1

This section reports the results obtained in the first user study. In the Figures 51, 52, and 53, the statistical analysis of the Collaboration Attitude is reported, as number of users for each group (respectively in the Figures 51a, 52a, and 53a) and means and standard errors (respectively in the Figures 51b, 52b, and 53b).

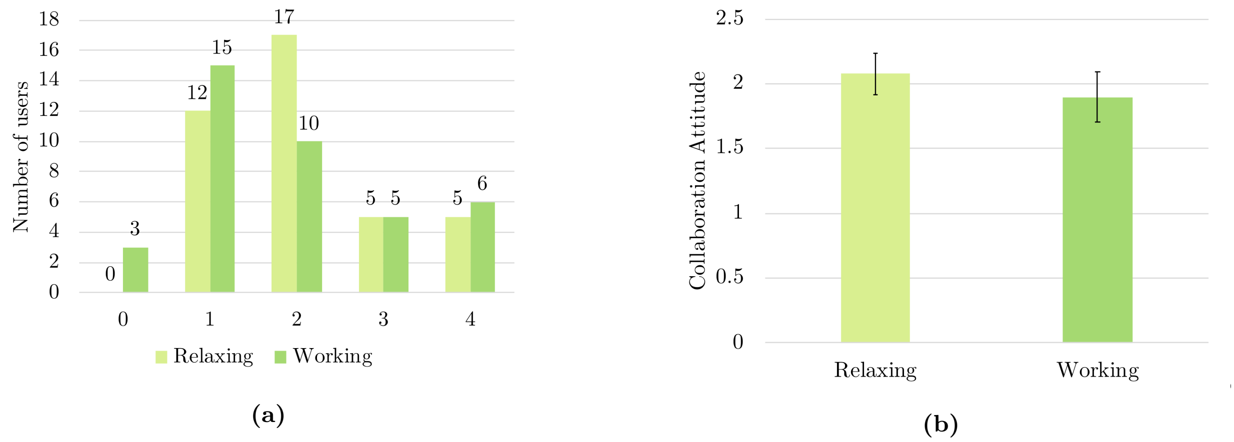


Figure 53. Collaboration Attitude analysis of the first user study with respect to the "Context" factor. (a) Users' Collaboration Attitude levels divided with respect to the "Context" factor; (b) Collaboration Attitude means and standard errors with respect to the "Context" factor.

Groups	Count	Sum	Average	Variance
Intimate	26	37	1.42	0.49
Personal	26	81	3.12	0.83
Social	26	37	1.42	0.41
Male	48	69	1.44	0.59
Female	30	86	2.87	0.95
Relaxing	39	81	2.08	0.97
Working	39	74	1.9	1.46

Table 5.1. Population statistics

The Proxemics setting that maximizes the Collaboration Attitude is when the robot approaches the human with a Personal distance (Figure 51b). This result is in line with other user studies conducted in Human–Robot Proxemics [239, 318, 235], stating that humans' comfort is maximized within the Personal setting. The Intimate and Social distances give lower values of Collaboration Attitude.

When looking at the gender of the participants (Figure 52b), the mean of the Collaboration Attitude obtained by females is strikingly higher than the males' one. This represents the first indication that females may be more inclined to help robots than males. The study of this factor is interesting, as it is known that males and females have different social behaviors.

Despite the Relaxing context seems to maximize the collaborative intentions of the participants (Figure 53b), the Collaboration Attitude is rather stable when different contexts are tested. As a consequence, the Context does not appear to be a perturbing factor for the Collaboration Attitude.

In order to search for significant variations and test our operational hypotheses, we performed statistical tests over the different datasets. In Table 5.1 a sketch of the sample under consideration is provided. The populations of Proxemics and Context factors are completely balanced, with a population of 26 elements for each Proxemics setting and 39 participants for both the Relaxing and Working groups. Conversely, the samples of the Gender factor are not balanced, with a majority of males with respect to females, i.e., 62% versus 38%. This might suggest that the homogeneity of variance assumption is not met and a One-way ANOVA procedure over the Gender factor might not be robust. Hence, we performed the Levene's test for homogeneity of variance over all the populations into account. Results are shown in Table 5.2. It is clear that for the Proxemics and

p **value**	**Mean**	**Median**	**Trimmed**
Proxemics	0.2131	0.2570	0.1768
Gender	0.0178	0.0322	0.0190
Context	0.0995	0.0794	0.0880

Table 5.2. Levene's test (proxemics, gender and context)

Src of Var	SS	df	MS	F	P value	F crit
Proxemics						
Btw. groups	49.64	2	24.82	42.95	3.71×10^{-13}	3.12
Wtn. groups	43.35	75	0.58			
Total	92.99	77				
Context						
Btw. groups	0.63	1	0.63	0.52	0.47	3.97
Wtn. groups	92.36	76	1.22			
Total	92.99	77				

Figure 54. One-way ANOVA results (proxemics and context).

Gender			
F	**df1**	**df2**	p **value**
46.53	1	51.25	1.02×10^{-8}

Table 5.3. Welch's test results (Gender)

Context variables, the p value of the Levene's test is always greater than 0.05; we thus retain the null hypothesis for the assumption of homogeneity of variance and conclude that the assumption of homogeneity of variance is met. On the contrary, for the Gender variable the p value is always less than 0.05. We reject the null hypothesis and conclude that the assumption of homogeneity of variance is not met.

Figure 54 shows the ANOVA results for Proxemics and Context variables, by reporting the P value, the sum of squares (SS), the degrees of freedom (df), the mean squares (MS), the ratio of the two mean squares values (F) and the F critical value (F crit).

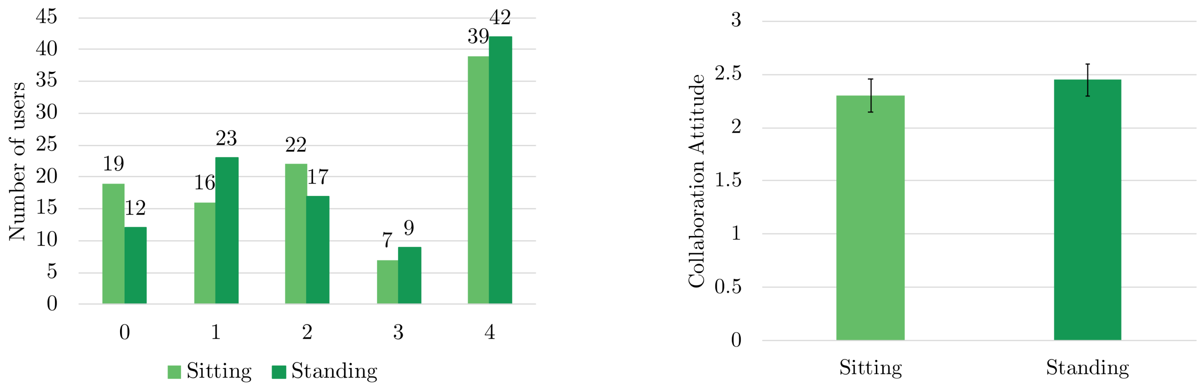
Table 5.3 shows the Welch's test results for the Gender variable, by reporting the P-value, the degrees of freedom (df1 and df2) and the ratio of the two mean squares values (F).

There is a significant effect of Proxemics on Collaboration Attitude at the $p < 0.05$ level for the three conditions (i.e., Intimate, Personal, and Social)[$F(2, 75)=42.95$, $p= 3.71\text{x}10^{-13}$]. In order to confirm the ANOVA results, we performed a post-hoc test through three t-tests, aimed at comparing each pair of groups. Table 5.4 shows the result of this additional analysis. As suggested by the means histogram, in the Personal distance the users in our population act differently w.r.t. Intimate and Social settings (the two-tailed p values are lower than 0.05), whereas users seem to behave similarly in their Intimate and Social spaces.

The Welch's test shows that a significant effect on Collaboration Attitude is also provided by Gender at the $p < 0.05$ level for the two conditions (i.e., Male and Female) [$F(1, 51.25) = 46.53$, $p = 1.02\text{x}10^{-8}$]. Conversely, there is not a significant effect of Context on Collaboration Attitude at the $p < 0.05$ level for the two conditions (i.e., Relaxing and Working) [$F(1, 76) = 0.52$, $p = 0.47$].

	Intimate vs. personal	Intimate vs. social	Personal vs. social
df	50	50	50
P(T <= t) two-tail	9.6×10^{-10}	1	4.1×10^{-10}

Table 5.4. t-test: two-sample assuming equal variances



(a) (b)

Figure 55. Collaboration Attitude analysis of the second user study with respect to the "Activity" factor. (a) Users' Collaboration Attitude levels divided with respect to the "Activity" factor; (b) Collaboration Attitude means and standard errors with respect to the "Activity" factor.

Groups	Count		Sum		Avg.	Var
Sitting	103		237		2.30	2.41
Standing	103		252		2.45	2.23
Src of Var	SS	df	MS	F	*P* value	F crit
	Activity					
Btw. groups	1.09	1	1.09	0.47	0.49	3.89
Wtn. groups	473.13	204	2.32			
Total	474.22	205				

Figure 56. One-way ANOVA results (activity).

p **value**	**Mean**	**Median**	**Trimmed**
Activity	0.8407	0.9292	0.8140

Table 5.5. Levene's test (activity)

5.2 User Study 2

In this section, we report and discuss the results of the second user study. Again, in order to analyze the collected data, we performed a One-Way ANOVA test. Here we focus on a more fine-grained discretization of the "Activity" that users are performing at the moment of the interaction.

Figure 55a shows the number of users grouped with respect to the CA value that they achieve and divided according to the two values of the activity factor. Figure 55b, instead, reports means and standard errors of the Collaboration Attitude. Interestingly, the plots show that "standing" users are slightly more inclined in collaborating with the robot, even though the statistical analysis (Figure 56) confirms that the CA values are firmly stable when different activities are compared. Thus, the Activity performed by the user does not appear to be a perturbing factor. The populations for the two values of the activity factor are balanced as 103 users participated for each of the configurations. Again, before performing ANOVA we test the homogeneity of variance through the Levene's test (Table 5.5), showing that the assumption is met.

Bottom of Figure 56 reports the ANOVA results while the top of Figure 56 reports the number of users, the sum of CA values, its average and variance for each of the considered settings.

Surprisingly, there is not a significant effect of Activity on Collaboration Attitude at the level $p < 0.05$ for the two conditions (i.e., Sitting and Standing) [$F(1, 204) = 0.47$, $p = 0.49$].

6 Remarks

The aim of our investigation was to identify which factors may influence the interaction between the robot and human in the context of Symbiotic Autonomy, namely when the robot approaches the human to ask for help. We have characterized the Collaboration Attitude and performed two user studies to identify whether proxemics, gender, context, and activity have an influence on it.

Not surprisingly, and in line with the findings of several works that address proxemics as a key factor in human–robot interaction, proxemics indeed plays a role. More specifically, this finding could be explained by two elements: the control that people exercise in their Intimate space and the perceived robot size. In fact, the presence of the robot seems to be not relevant, when the interaction takes place at longer distances. These results are particularly interesting in the framework of Symbiotic Autonomy: they suggest that a robot asking for help should approach the user in his personal space, as this distance seems to be the most comfortable for the population of our user studies.

The results obtained over the Gender factor are supported by the work in [239]. In their user study, in fact, male users are more diffident and place themselves significantly further from the robot than females. These results are also confirmed in the work in [317]. Specifically, they report a considerable difference of the comfort level within the intimate area when varying the gender of the users. Their results support that males impose a dominant territory that the robot is violating if it is positioned in their intimate areas. In Human-Human interactions, manifold psychological studies address this particular behavior. For instance, the difference in cooperating between males and females has been pointed out in [127], where this evaluation is made upon the well known Dictator Game. A further confirmation is provided by [307], where the gender dimension is analyzed within an experimental study of team performance. In conclusion, our results in the setting of Symbiotic Autonomy report that female participants show more interest in exploring a new collaboration with a robotic partner. Therefore, the robot behavior could be leveraged by allowing the robot to seek for help first by female subjects.

While this is an interesting confirmation that space and physical approach of the robot must be carefully considered in designing also symbiotic robots, our aim was also to understand whether what the user is doing is also relevant. In other words, we intended to test whether it is worth trying to characterize the situations where it is more effective for the robot to ask humans for help. In our first study, we studied the Context (i.e., Working vs. Relaxing) and our initial hypothesis relied upon the intuition that our users in a relaxing context are more inclined to a collaborative behavior. The results of the experiment show that there are not statistically significant differences when changing the operational context. This finding could be explained by a strong focus on social interaction with other humans in a relaxing domain and it may suggest that robots are not yet considered "social" partners. This factor trades off the nature of the working context, where people are usually busy in their tasks.

As our first user study did not provide a clear answer to our question, we implemented a second user study trying to provide a better characterization of the situation in terms of the activity performed by the user (i.e., Standing vs Sitting). However, somewhat unexpectedly, the analysis of the data collected in the experiment indicates that our population does not show a different attitude depending upon the activity variable. It is worth remarking that "activities" have been determined in accordance with elements that are recognizable through robot perception capabilities. In other words, we identified activities that the robot will be able to detect through its own sensors. Hence, our findings can not be generalized to situations where the robot has a much deeper understanding and the general question of the influence of the situation on the robot's choices in a Symbiotic Autonomy framework requires further investigation. Such an outcome can have several justifications that we address in the following. First, the coarse and simplified characterization of the human activity might prevent the strong bias we were expecting when designing the experiment. As an example, a sitting person might be more busy than a standing one. Hence, we speculate that a more detailed categorization of the activity could help in polarizing the Collaboration Attitude. Second, the embodiment of the robot prevents the establishment of an interaction between the robot and the user at the emphatic level. Moreover, as a direct consequence of the previous remark, robots are not yet considered as social partners and their presence within the environment is still seen as a novelty factor. Finally, people may consider the robot requests not plausible as they were expecting to act as operators commanding the robot. In fact, the way humans interact is strongly related to how the social partner is considered and perceived. This last issue seems to strongly bias interactions and collaborations [106] and surely needs to be the subject of further investigation.

Chapter 6

Evolving User-Centered Design towards Participatory Design in Service Digitalization

1 Introduction

At the turn of the 20th century, new technological advances such as electricity, flight, and the gasoline engine changed tremendously the shape of the world and gave rise to a feeling of *techno-optimism*, based on the belief that technology can significantly and continually improve the lives of people, by fostering increased standards of living or, in a broader sense, better conditions of life.

In the late 20th and early 21st centuries, techno-optimism has found expression in new forms of social technological breakthroughs, such as smartphones and social networks, whose aim is to improve the interaction, communication and collaboration among people, by providing them the freedom to voice and express their own ideas and opinions. According to Rushkoff [289], advancement in social technology is an important means to reduce the inequalities of power and wealth.

While the Rushkoff's view of techno-optimism [289] does not disregard the problems that technology may cause, the identification of *social progress* with *scientific and technological progress* is a subtle topic strongly debated in the Information and Communications Technology (ICT) community. In a recent editor's letter published at the Communication of the ACM journal [334], the Editor-in-Chief Moshe Vardi has tackled the above issue by discussing the role of technology in the creation of democratic societies. Vardi, as many other ICT researchers, marries the cautious approach of Kentaro Toyama [322], which argues that "*using technology to solve societal challenges requires a deep understanding of the societal context*" and that "*deploying technology without understanding its societal context may have adverse societal consequences*".

In the ICT community, adapting technology to human nature is the key concern of User-Centered Design (UCD). UCD is a design philosophy that places the end-users (as opposed to the "thing") at the center and involves them in the systems design process [245, 122, 161].

However, end-users involvement in UCD does not lead to more user influence in terms of either user empowerment or democracy. This because UCD neglects the social dimension of technology: users are consulted in the design process, but they do not have any direct involvement or creative control over the developed technological solutions. This may generate an unbalanced empowerment that makes difficult to bring socio-technical conflicts into the open and, consequently, to realize "socially-accepted" technologies.

On the other hand, the collaborative and social nature of the design process is getting increasingly explicit in the Product Design community, where Participatory Design (PD) approaches (originally *co-operative design*, now often *co-design*) are employed to actively involve stakeholders, designers and end-users in the creative process of new products. In PD, participants are involved during all the stages of a creative process, ranging from the initial exploration and definition of the problem to the product development and its evaluation.

While in the ICT research literature there are attempts to incorporate some of the perspectives of PD into UCD, the fact is that the majority of resulting approaches treats PD as a banal form of UCD to solve specific local usability issues rather than to empower end-users to intervene in the various stages of the design in a democratically reasonable way.

In this research, after providing a deep analysis of the state of the art of PD in both the ICT and Product Design communities (see Section 2), we investigate how the integration of the unique features of PD into UCD not only sought to intervene upon situations of conflict through developing more democratic processes, but also lead to create *innovation* in the design process. We advocate that such innovation can be obtained by giving the right voice not only to the users who reach consensus in the design process, but also to the marginals. We provide an explorative simulation model based on evolutionary computing and some experiments to support our claim (see Section 3). Furthermore, we present a sketch of a Visual Analytics system that can be used to support the user interaction in the participative process (see Section 4). Finally, in Chapter 7 we draw some conclusions about the system's main findings, providing a critical discussion about the general applicability of the approach, and tracing possible directions of future work given the abstract context of user-oriented service digitalization and innovation.

2 Related Work

User-Centered Design (UCD) is a design philosophy where the end-user's needs and limitations are given extensive attention at each stage of the design process and development lifecycle [122, 37]. Nowadays, UCD is increasingly seen as essential for the creation of successful products and prototyping ICT applications, in order to minimize and prevent product failures at the end [83, 126].

In the UCD process, special attention is paid on ensuring that the *thing* being designed (e.g., the service, system, technology, etc.) meets the needs of the *end-users*. In UCD, three main actors are usually involved in the design process: the researcher, the end-user and the designer [45]. The researcher is in charge of collecting primary data and to investigate secondary sources to learn about the needs of the end-users. Such needs are then converted in the form of design criteria, which are interpreted by designers (often) through scenarios. Finally, the focus shifts on the design development of the thing and on its evaluation through usability testing, which requires (again) the feedbacks of the end-users.

While UCD strongly involves cognitive factors (such as perception, memory, learning, problem solving, etc.) as they come into play during the interactions with the users, its attitude is to design *for users* rather than *with users*, by relegating the role of the users to a means to realize "better design". According to [344], "better design" may mean "better for all", but usually it just means "better for those who decide", that in UCD are the designers and the researchers.

In the Product Design community, the exploitation of Participatory Design (PD) approaches blurs the roles of the designer and the researcher; conversely, the user becomes a critical component of the whole design experience. In this context, PD is not simply seen as a design method, but as a mindset based on the belief that people want to express themselves and to contribute proactively in the design development process.

Recent works in Product Design suggest that large-scale design participation could help achieving not only sharing but also innovation. Obviously drawbacks exist in PD, including the need of dealing with the lack of experience of most of the users-producers and the necessity of motivating them.

In the following sections, we first discuss in detail the research attempts performed in the ICT community to integrate the features of PD into UCD (Section 2.1). Then, we investigate the state of the art of PD in the Product Design community (Section 2.2), by analyzing the concepts of consensus and innovation in large-scale design participation (Section 2.3).

2.1 Participatory Design in UCD

The connection between ICT and PD has Scandinavian origins and emerged in the 1970s as a means to rebalance power among managers and workers [63]. In those times, in many countries, social democratic parties had a strong influence on people, the majority of workers belonged to trade unions, and social welfare provisions were indisputable. Therefore, workers and their organizations were seeking to establish methods to influence the development of ICT nationally and internationally, and this kind of engagement was seen as part of democratic agendas across the board [49].

In that context, the PD approach aroused considerable interest, as it provided both a theoretical rationale along with concrete methods for involving users. In the 1990s and 2000s, PD research developed further to include a strong interest in cases and methods from the Human-Computer Interaction (HCI) field [49]. Starting from that, many research has been conducted to explore the role of PD in reshaping the UCD process and its methods under the umbrella of HCI. However, PD has been often seen as a more neutral form of UCD, thus losing its original "social" attitude.

In the last years, there was an attempt to rediscover the original meaning of PD and to incorporate its social features into UCD. To this extent, in the range of the 2016 ACM Conference on Human Factors in Computing Systems (CHI 2016), Bødker presented a course introducing the theory and practice of PD by providing the participants with the opportunity to work on a PD sample case [65]. Similarly, in the range of the 15th IFIP International Conference on Human-Computer Interaction (INTERACT 2015), the workshop "Mediation and Meaning in HCI" [64] was organized to investigate computer mediation in human communication and action, with a special focus on mediation in UCD against the backdrop of PD. Then, the workshop "Participatory design and the humanist landscape" [182], held in conjunction with the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing (UBICOMP 2015), was thought to investigate the use of PD methods in the context of design for wellbeing. Last but not least, in 2018, Bannon, Bardzell and Bødker organized a special issue of the ACM ToCHI journal on "Reimagining Participatory Design" [48], with the aim of collecting research contributions that were able to reshape and evolve the traditional features of PD towards the dynamicity of the today's technological-driven world.

In this same direction, several research works have been proposed over the years. The work [335] questioned whether involvement of users and stakeholders in design processes can hold up in practice, particularly as participation takes on new meanings and incorporates new perspectives. The work [292] analyzes critically the concept of "user participation" by unfolding the concept itself across different levels of participatory configurations. Further, [341] compares PD approaches against the traditional UCD ones for product development, by emphasizing that the formers can help to enhance the overall user experience, thus making the product developed potentially more attractive for the market. According to [119], PD activities are a form of *learning* that is closely tied to metacognition (i.e., cognition of cognition) and allows users to exploit their past experiences to improve the design process. The work [62] investigates the appropriate relation between studying the work practices of the workers for whom new technologies are being developed and directly engaging workers in design. In addition, [268] uses the lens of PD to contrast two different approaches to citizen science: one that puts citizens in the service of science and another that involves them in the production of knowledge. Finally, while [138] proposes a "tool-to-think-with" to drive PD practitioners in a process of critical reflection on their work, [190] presents a democratic approach (developed through a work on telehealth in Denmark) to improve the influence of the users on the design of ICT systems.

In the context of the aforementioned special issue on "Reimagining Participatory Design" [48], five interesting contributions have been published. The paper [123] examines PD with vulnerable groups, focusing on a project where young forced migrants are pushed to collaborate with members of the host community in order to help developing a technology-based tool to support their resettlement. In [52], exploiting the case of a urban renewal project in Taiwan, the authors propose a cooperative engagement between PD research and feminist utopianism (that is considered as highly process-oriented, participative, and emergent) at the levels of theory, methodology, and on-the-ground practice. In [66], starting from a critical discussion of the current state of PD, the authors present a set of ingredients (such as changed partnership with users, new roles of researchers as activists, more democratic control, etc.) to revitalize and revise PD towards helping people to tackle large-scale projects. The paper [258] addresses the role of PD in the public sector, investigating new ways of engaging civic participation with specific public sector projects, using social media/community technologies. Finally, in [144], the authors claim that current methods for engaging urban populations in PD activities are somewhat limited and describe their approach to empower socially disadvantaged citizens, using a variety of both social and technological tools, in a Smart City project.

Since nowadays digital and mobile technologies are increasingly used in health and social care, the application of PD to improve the overall quality of design has been also studied in such challenging domains. In this direction, the work [118] shows how research on PD can improve the experience of motherhood. This claim is supported by an analysis of data collected from a design process that includes over 1000 mothers involved in submitting ideas to improve the breast pump, a technology that allows mothers to collect and store their breast milk. The work [204] addresses the aging population phenomenon, and suggests the engagement of older adults in PD activities. Such an intuition relies on the fact that the perception of older people attitudes towards technology changes over time, and this may help design teams to deliver the appropriate design for the elderly. The work [270] applies PD for evaluating the effectiveness of gesture sets to search information in multi-touch tablets when the users involved in the searching task have little or no experience with touch screen devices.

Research on PD has also developed methods to empower people with impairments to actively take part in the design process. This issue has been recently tackled by the workshop "Empowering people with impairments: How participatory methods can inform the design of empowering artifacts" [332], held in 2016 in the range of the 14th Participatory Design Conference (PDC'16). The target of the workshop was to discuss about best practices to design for- and with people with sensory-, cognitive- or social impairments. Similarly, the work [231] described challenges and lessons learned from PD through involving people with dementia in developing a mobile touch screen based assistive tool for them.

PD has been also utilized in the health sustainability of communities of family farming, where [111] proposes a methodology for the development of applications for mobile devices geared to popular health education that can contribute to the rational use of medicinal plants and herbal medicines in Brazil's countryside. Considering the ethical part while including participants in the design process, the work [272] highlights the challenges considered in a standard ethics review when working with children in PD activities.

2.2 Participatory Design in the Product Design Community

Today the word "design" is used in a variety of ways; much of the design tradition derives from architecture and Industrial (or Product) Design, which is often connected to other disciplines such as Graphic Design. Ever since (Industrial) Design became a formalized profession, the collaborative nature of the design process is getting increasingly explicit.

In Design Methods, the work [174] advocates taking on a "glass box" approach to design in order to promote collaboration, as opposed to the "black box" approach to design that hides and mystifies the creative process. Today, both the scope and the toolbox of design continues to broaden. On the one hand, designers tackle more complex problems (social, environmental, business...) with systematic approach, on the other hand they adopt new intellectual tools, learning "satellite" skills from other professions, such as ethnography, gradually opening the new product/service development process toward end-users. As [220] expresses, "*in our connected world, where everybody interacts with everyone else almost independently of time and distance, this separation of the design team from the rest of the world no longer stands.* [...] *So, in a connected world, all designing processes are in fact co-designing processes* [...]".

The success of multi-, inter- and trans-disciplinary practices such as IDEO[1] have demonstrated the potential of high quality collaboration, which they actively disseminate through various mediums, from design toolkits (e.g., Design Kit: The Human-Centered Design Toolkit) to the influential publication of Change by Design [72], which has helped to establish the central role of Design Thinking in the contemporary design discourse and rhetoric. As noted by [60], Design Thinking is in a certain sense a continuation of the socially sensible PD tradition that emerged in Scandinavian countries in the 1970's, albeit with a better articulated and more appealing rhetoric. This suggests that designers, rather than being obsessed with products (things), should consider (1) the big picture of socially innovative design, (2) open up for a collaborative effort with all stakeholders, through a (3) hands-on approach of exploration with design and prototyping.

In the Design disciplines (especially in the European context), the principles of Design Thinking and PD have resulted a significant body of research and practice focused on the concept of Social Innovation, theorized and promoted by institutions such as the Young Foundation [242] or the DESIS Network (Design for Social Innovation and Sustainability). Social Innovation leverages on the involvement of people for the development of projects and their collaborative interaction as users/co-producers or any other form of participation to the initiative. Co-design can be intended as a complex and a wide process where individuals and groups can take part interacting and conflicting for the development of projects with a social or community relevance. In this regard, [220] recognizes that we are living in a connected world, where socio-technical systems and infrastructure are drawing distributed networks of food, fabrication, energy, water, culture, and so on. [220] claims the emergence of the SLOC scenario, which stands for Small, Local, Open, Connected: "*Individually, each adjective and its implications are easily understood, but together they generate a new vision of how a sustainable, networked society could take shape. [...] this SLOC scenario could become a powerful social attractor, capable of triggering, catalysing, and orienting a variety of social actors, innovative processes, and design activities*".

Castells has been studying the rise of the network society since the beginning and he stressed on the nature of the architecture of the network, which needs to be open, decentralized, distributed, multidirectional and interactive [82]. At the same time, he emphasized on the fact that "*the users can also be the producers of the technology, while adapting and transforming it to their needs and use*".

The new scenario brought by the maker movement has just started a revolution in the way we produce physical objects, developing local factories and personal fabricators taking advantage of a worldwide community of peers [140, 90, 163, 164, 165]. If industry is living an historical shift of its role within society and production, open design and distributed microfactories are in the position of independently incorporating all the productive aspects, from the concept, to the manufacturing, to the communication and the distribution, and even the crowdfunding of the project [163, 164, 165]. Even if this is the very beginning of a long process, we can see how the new generations of designers have come to terms with deindustrialization and at the same time are becoming aware of their service and strategic role concerning innovation. The process of digitalization is leading to the transformation of the nature of the enterprises, while opening to micro-factories and "personal capitalism", able to share locally and globally skills and knowledge, as well as resources and tools, to the accomplishment of projects and products.

On the other hand, the border between the designer and consumer is dissolving not only due to the increasing interaction between them during the conceptual design phase or social innovation projects, but also because consumers have an increasing voice in diversifying the production according to their specific needs, through a different kind of participative practices. Recognizing the emerging possibilities of introducing ICT in the mass manufacturing pipeline, resourceful industries have started to practice mass customization, demonstrating that open-ended design can be highly desirable for many users. Based on the first two decades of research and industry experience, authors of [259] have collected numerous methods and case studies in their Handbook of

[1] see: https://www.ideo.com/eu

Research in Mass Customization and Personalization. To summarize the findings, [294] highlights the importance three key ingredients of mass customization: (1) adequate Solution Space, (2) Robust (manufacturing) Process and (3) intuitive Choice Navigation. The latter two are getting easier to fulfil thanks to advancements of information technologies (digital fabrication, generative design tools, web applications and frameworks, etc.). Conversely, finding the right Solution Space continues to be challenging, as it involves identifying the product attributes along which customer needs to diverge.

Talking about their experience with a participatory mapping project, [120] warns about the often occurring "*false notion of a standing motivated public willing and eager to participate*". Instead, they argue that "*such publics are constructed: systematically, brought together, ordered, and maintained through the actions and influence of designers and researchers*". In order to provide a stable foundation for participation, it should be clear what keeps the public together in an actual community: for example, [41] classify (online) communities according to four possible orientations: transaction oriented, interest oriented, fantasy oriented or relationship oriented.

2.3 Consensus and Innovation in Large-Scale Design Participation

Conventionally, the design profession tends to sample prospective users and closely observe them, or collaborate with them in the case of PD. This is a qualitative approach to the user needs, as opposed to the more quantitative approach of the marketing profession. However, in recent decades, as the market matured and mass customization practices emerged, certain industries started to observe that recorded user choices can be considered as actively probing users for *aesthetic consensus*, which in turn can help to achieve (mostly incremental) *design innovations* which are desirable also for a wider public, thus contributing to the evolution of mainstream designs [294].

As opposed to the demiurgic idea of the designer as the sole source of creativity, the design profession is increasingly accommodating the concept of *prosumers*, the mixture of producers and consumers, as coined by [320] to mark the new actor who is motivated to contribute to the design process of their goods. The prosumer dealing with service society and digital networks is opening a hybrid economy, halfway between capitalism and the collaborative commons [279, 280, 281]: transportation, time, knowledge, even tools can be produced, shared and customized. In order to achieve a consensus between the designer's project and the user's preferences, [110] suggests that the designer "*should become a metadesigner who designs a multidimensional design space that provides a user-friendly interface, enabling the user to become a co-designer, even when this user has no designer experience or no time to gain such experience through trial and error*". While user diversity can be considered an important resource for innovative products with high emotional value, [100] also notes that providing adequate guidance for the user participation is crucial: "*with too much structure the outcomes are controlled by the hidden hand of the designer and people are simply selecting from a range of options laid down by them. Too little support and many potential creative contributions are lost because starting from a blank page is difficult, even for experienced designers.*" Thus, meta-design can be perceived as a design for designers [132]. Based on the assumption that not all future uses and users can be foreseen at design time, meta-design creates *open systems* which can be modified by the users who act as co-designers at use time.

Talking about complex computer systems, [130] proposes the seeding, evolutionary growth, and reseeding (SER) model, an iterative approach based on the idea of starting with a small thing (seed) with the potential to grow and change over time. According to this model, meta-designers start with building "incomplete" or "underdesigned" seeds, but then leave users the possibility to help the evolution of the system with the large number of small contributions. Alternating back to more planned activities by the meta-designer, reseeding means a deliberate restructuring and enhancement of the system. The practical value of this approach has been demonstrated also by others, for example [146] has applied the SER model to the iterative development of NatureNet, a participatory citizen science portal. [131] argues that this meta-design approach can be valid not only for software artefacts, but also for a variety of other fields, including physical artefacts: this is facilitated by digital fabrication technologies, which minimize the initial investment and maximize logistical flexibility, allowing for the gradual evolution of a design.

While there are numerous mass customization platforms that tap into the creativity of users (both large industries in like shoe manufacturers and smaller ones like Nervous Systems, Makies dolls, Opendesk, Sketchair), they are usually quite limited regarding the morphology and typology of the products, due to the inherent limitations of computer 3D modelling technologies, particularly in the browsers' limited resource environment. Hence, as of today there are not many effective applications of a SER model for physical products: significant (unforeseen) evolutionary growth is seldom handled effectively, making also reseeding rare.

Elaborating on the idea of consumer cultures shifting to cultures of participation, [131] notes the emergence of new, middle ground models with different levels of participation and expertise; beyond prosumers, there are also professional amateurs, social production and mass collaboration. In order to ensure the productive involvement of these different, potentially useful figures, a highly structured way of collaboration might be necessary. For example, [155] has experimented with a system characterized by delegation patterns, organizing participants into a User Parliament, overseen by a Central Committee, comprising both representatives of the initiating company and prominent members of the user community, in order to ensure that they have an actual voice in the final decision. An even more structured, commercial example is Quirky, which relies on selected "inventions" from an online community, developing these inventions in collaboration with an internal team of designers, engineers, researchers, and marketers. "Inventors" are encouraged to elaborate their ideas with other members (influencers) before submitting a thorough concept for the community voting. When (and if) the product gets to manufacturing, the inventor receives royalties along with the all other influencers, everyone according to the importance of the contribution; an incentive that aims to create a sustainable mechanism of continuous market-driven innovation. The precise tracking of the so-called "influencers" is an ambitious attempt to quantify contributions within Collective Intelligence-based projects, and also a noteworthy crowdsourcing model that might spread in the future.

However, as [131] notes with a tone of criticism, the above cited platforms often operate more as a content management systems with limited (if any) possibilities to evolve the crowdsourced proposals by building on others' ideas. One interesting example is the experimental platform Endlessforms.com, which allows the evolution of 3D geometries through a browser interface, which takes user input as the driving force of selection [92]. Still, as there is no strong incentive for contributions, there is no significant activity (nor an active community) on the website for the last few years. "*Participation is predicated upon delivering value to those who participate*", as [71] notices, should be a principal consideration during participative projects. According to [303], this weakness of open innovation platforms is often an inherently set by the owner organizations who consciously or unconsciously limit the dialogue between their users during the typical methodologies such as idea competitions, focus groups or idea platforms. Another major challenge for the application of existing participative software systems (PSS) during the New Product Development (NPD) process is the organization of a collaborative social ecology, which usually does not emerge automatically, but needs the conscious effort of coordinating the stakeholders in order to create the optimal conditions for their productive participation [348].

3 Methodology: An Explorative Simulation Model

In this section we present our simulation model based on evolutionary computing designed to explore the differences between UCD and PD with respect to innovation and consensus. To the best of our knowledge, this is one of the first attempts for the computation of metrics capable of providing insights for a quantitative comparison of the two approaches.

The rest of the paragraph is organized as follows: in Section 3.1 we introduce a case study for the model described in Section 3.2. The model is discussed in view of the scientific literature in Section 3.3 and finally, in Section 3.4, we present our experimental results.

3.1 Case Study

In the last years, there was a growing interest in providing non-expert users with services for automatically designing graphical artifacts in a few steps, as a result of a *binary feature selection.* A concrete example is represented by the arising of several online logo generators, which allow one to create a professional logo just by answering a number of questions about the own style preferences.

Such tools require some details on the name and kind of business one wants to represent with the logo (e.g., a coffee shop called "Example", cf. Figures a and b in 57). Starting from this knowledge, they automatize the creation of the logo by involving the user in the selection of a subset of the logo features, e.g., one can choose between icon-based or font-driven logo generation, cf. Figure c in 57. Then, like an optician, they start to perform several 'A' or 'B' tests to understand which fonts, shapes, icons and colors a user prefers for representing her/his brand at the best. At the end, the user is presented with a small number of logo drafts, all approximations of the preferences previously expressed. Such drafts can be selected, edited and finally bought. A simple example of encoding the features of a product in a *digital chromosome* is shown in Figure d in 57, in which the product p is a logo.

3.2 The model

In this section we propose a model to explore our case study in view of the experience made in GENDE [338] on the use of Genetic Algorithms in product design. In GENDE, the main *features* of a product p are encoded in a digital *chromosome*, and a population of random products P is initially generated. Such a population evolves generation after generation according to a fitness function that is computed on the basis of the users' feedback on the perceived quality of the individuals in the current population. More specifically, all the couples of individuals are shown to the users in matches, asking them to select the ones they like the more. The fitness function for a given individual is proportional to the number of likes it received. The whole process is depicted in Figure 58.

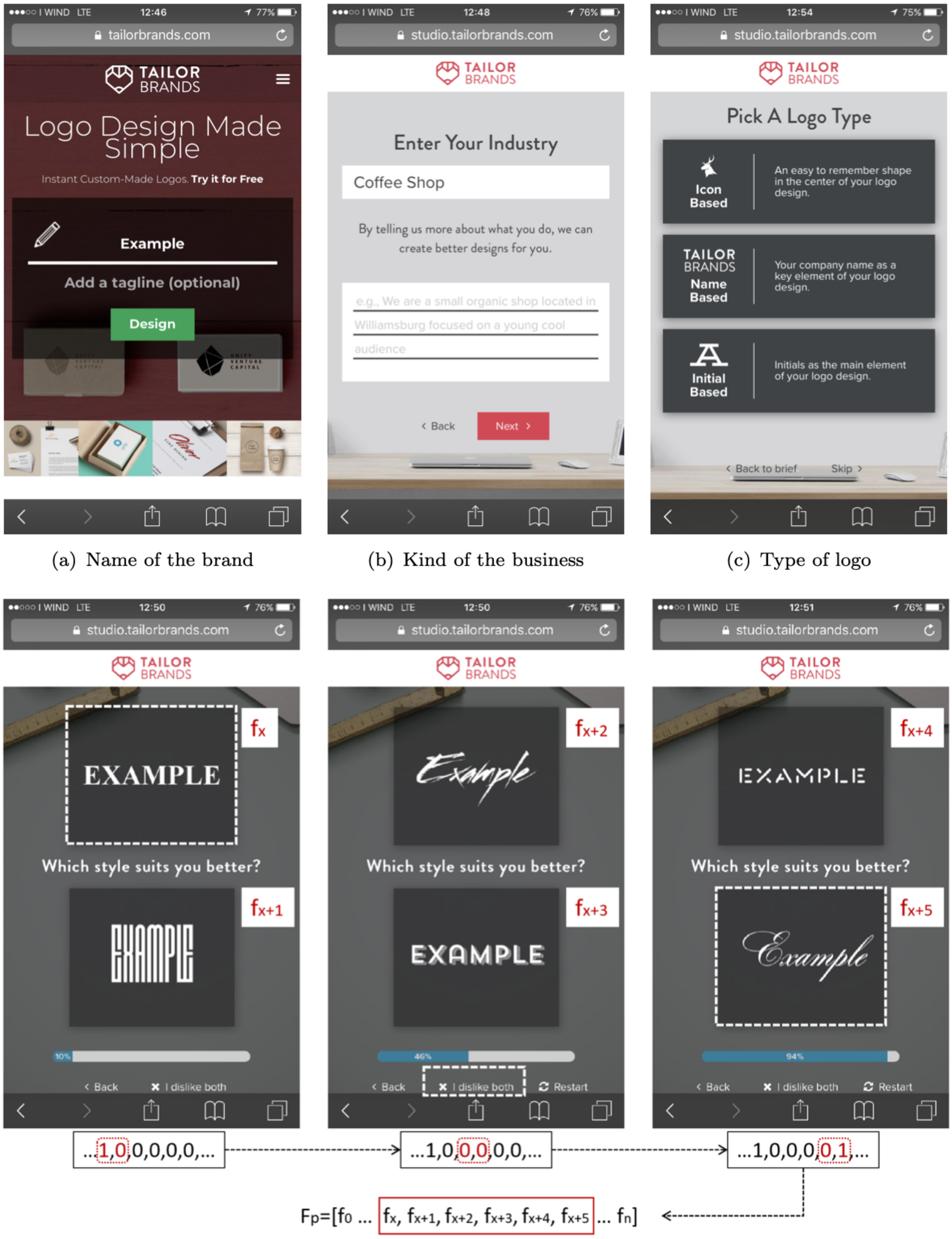
Notice that, as it has been originally conceived, GENDE is an example of UCD; indeed users can drive the evolution of the population of products P according to their feedback, but cannot directly change the features of the individuals as it is expected in PD.

We assume a product p is described by a *digital chromosome*, namely an n-dimensional binary vector F_p of features, in which a *one* in position i means that the feature i is present in the product, while vice-versa the *zero* means its absence. Notice that due to the nature of digital computation, this is a possibly inefficient but powerful representation, that can be easily adapted to represent scenarios in which features are not only binary (i.e., presence/absence). In Figure d in 57 we show the section of the chromosome correspondent to the choice proposed to the user.

Similarly, we assume that each class of users U is described by a binary vector F_U of the same size of F_p in which a *one* in position i means that the users in that class like the feature i. In such a simplistic framework, a natural measure of the appreciation of a class of users for a product is the hamming distance $|F_p - F_U|$. As smaller is such a distance as more is the appreciation of the class U for the product p.

As already observed, the original design of GENDE is an example of UCD: we simply evaluate $|F_p - F_U|$ for each individual in the current population as a proxy for the feedback of the class of users U for the product p. As much $|F_p - F_U|$ is close to *zero*, as much the feedback is positive.

To handle PD we should allow the users to change the chromosome of some of the individuals in the population P of products. To this purpose, we introduce the function $pd(r, c, U)$ that selects randomly a fraction r of individuals in the population P and changes at most a fraction c of their features such that the selected features in the individual are equal to the corresponding features in F_U. Since F_U describes the taste of users in U, this means that the users can change the product



(a) Name of the brand
(b) Kind of the business
(c) Type of logo
(d) Features selection

Figure 57. An example of encoding the features of a logo in a digital chromosome. Here we only focus on the features describing the font of the logo. Credits: https://www.tailorbrands.com.

chromosome, and consequently the product itself, according to their tastes. Indeed, in our model, the genotype (i.e., the chromosome) and the phenotype (i.e., the product as it appears to the users) coincide.

As an example, if $F_p* = [0,0,0,1,1,0]$ is among the r individuals selected by pd and $F_U = [0,1,1,0,0,1]$, assuming that $c = 1/3$, pd can change at most $1/3$ of the features of F_p*

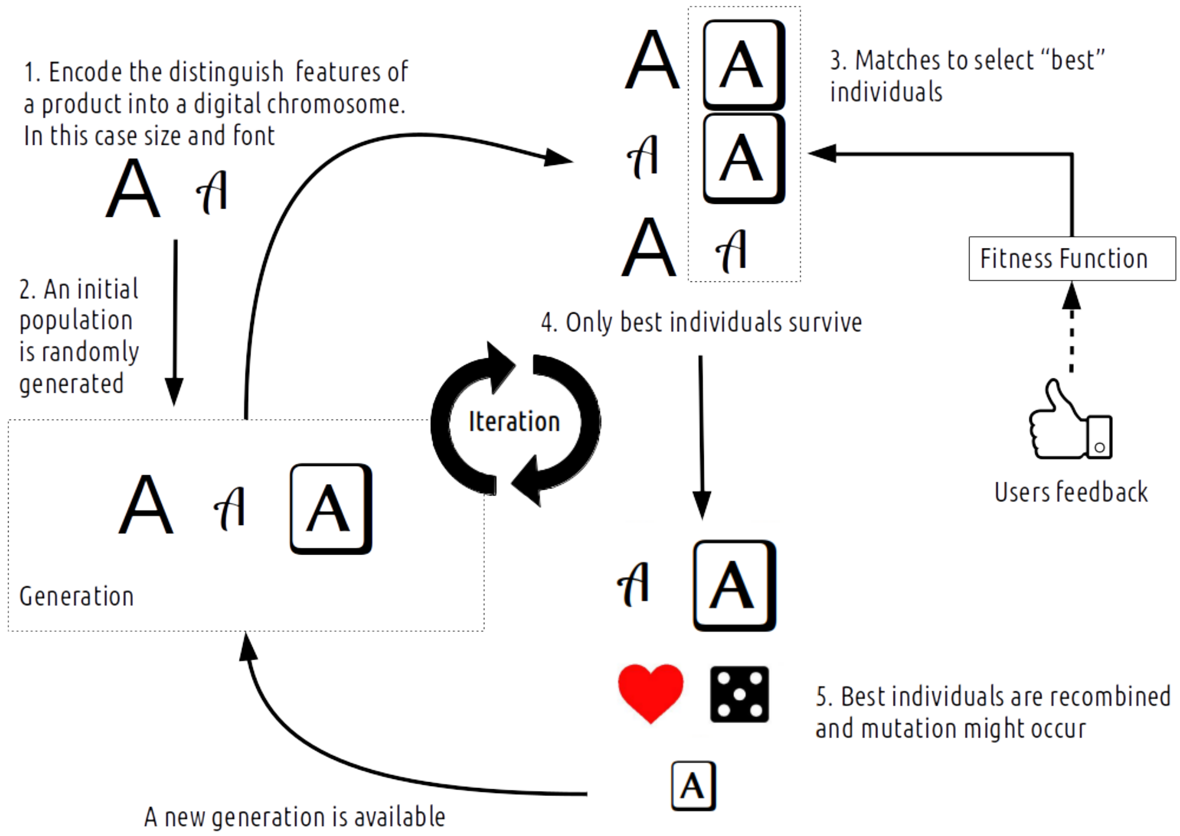


Figure 58. A Schema of GENDE process. In this example, the font and size of a character are encoded in a digital chromosome. In step 4, the matches are always win by individuals on the right.

and consequently both $[0, \mathbf{1}, \mathbf{1}, 1, 1, 0]$ and $[0, \mathbf{1}, 0, 1, 1, 0]$ are possible outcomes of *pd* in which the bold character represents the changes to make F_p* more closer to U taste. To some extent, this is equivalent to a "good" mutation of at most c genes in the chromosome of r individuals of the population. Notice that the mutation is good, because it always improves the fitness of the selected individuals for a specific class of users (i.e., U). Indeed, in the given example, originally the fitness function $|F_p * -F_U|$ was 5, while after the application of *pd*, the value of the fitness function is respectively 3 and 4

Consensus. We define *consensus* as the ability of the system to converge over generations towards an asymptotic value reducing the standard deviation, namely the fitness function converges toward and asymptote.

Evolution. We define *evolution* the consensus toward an optimum value, in our case the fitness function is minimized.

Innovation. We define *innovation* as the gradient of the evolution process. In other words the signature of innovation is a marked slope in the evolution process.

3.3 Discussion

In a recent research, Loreto et al. [210] succeed in proposing a model of the emergence of the new and its regularities. In that paper, the evolution is considered "*as a path in a complex space, physical, conceptual, biological, technological, whose structure and topology get continuously reshaped and expanded by the occurrence of the new*". In this perspective, the adoption of genetic algorithm is a natural choice to explore such a complex space [234]. In the context of time series, innovative outliers (IO) [137] are defined as an unusual innovation in the generating process that affects all later observations [85, 80]; in other words, the innovation produces a discontinuity in the generating process.

A recent paper by Papadimitriou et. al. [208] explored the concept of evolution, and sex in particular, from an algorithmic perspective. A significant result in that paper is that: "*There is a mismatch between heuristics and evolution. Heuristics should strive to create populations that contain outstanding individuals. Evolution under sex seems to excel at something markedly different: creating a good population.*" A natural question arises: Is a similar idea applicable to innovation or innovation is by nature the outcome of outstanding solutions? In our experimental results we assume the latter is true and we will focus on the outcome of the best individuals rather than on the whole population.

Most similar to our approach, in [181] the authors explore the concept of innovation using the metaphor of the biological concept of an evolutionary fitness landscape. Incremental and disruptive innovations are seen, respectively, as successful searches carried out locally or more widely. The concept of consensus is explored in the framework of digital evolution in [185] where the authors show that while genetic heterogeneity increases the difficulty of the consensus task, a surprising number of individuals were able to overcome these obstacles and evolve a cooperative behavior.

3.4 Results

We have implemented the proposed model in DEAP [136] and the results have been obtained averaging the outcomes of 50 runs. Each run is made of a population of 300 individuals that evolve in 50 generations. The size of F_p and F_U is 100; namely products are defined by a binary vector of 100 features. We consider 2 classes of users A and B that differ by 60% of the features. Crossover probability is 0.7 and mutation probability is 0.2. The function $pd(r, c, U)$ has $r = c = 10\%$, simulating that each class of users changes in a random way up to 10% of features on 10% of the actual population. As already observed, to drive our conclusion on innovation and consensus, we will only focus on the best individuals of the population, namely on the individuals minimizing the fitness functions.

Figure 59 shows the behavior of the fitness function of the best individuals. According to our definition of consensus, the fitness function is converging towards a minimum value both for class A and class B of users, while the standard deviation remains similar in all the generations between 1.4 and 2.4. However, remarkably, PD converges faster for both classes.

Figure 60 shows the gradient of the fitness function of the best individuals, namely what we defined evolution. A gradient equals to zero means no evolution. Since we are considering a minimization problem, the gradient is always negative. According to our definition of innovation, bigger gradient correspond to a more significant innovation. Interestingly, the gradient of PD is always bigger than UCD in the first half of the generations, while in the second half the values are more noisy and in some cases UCD prevails. This seems to suggest that PD fosters more innovation in the initial stages of the evolution. While evolving towards a better product over the generations, innovations becomes more difficult; indeed the module of the magnitude of the gradient is smaller. This seems to confirm the intuition that as much the products are close to the ideal product, as smaller is the probability of innovating.

Similar results can be obtained in a "symmetric" case in which crossover probability is 0.2 and mutation probability is 0.7. In Figure 61 the cumulative distribution of jumps in the fitness function

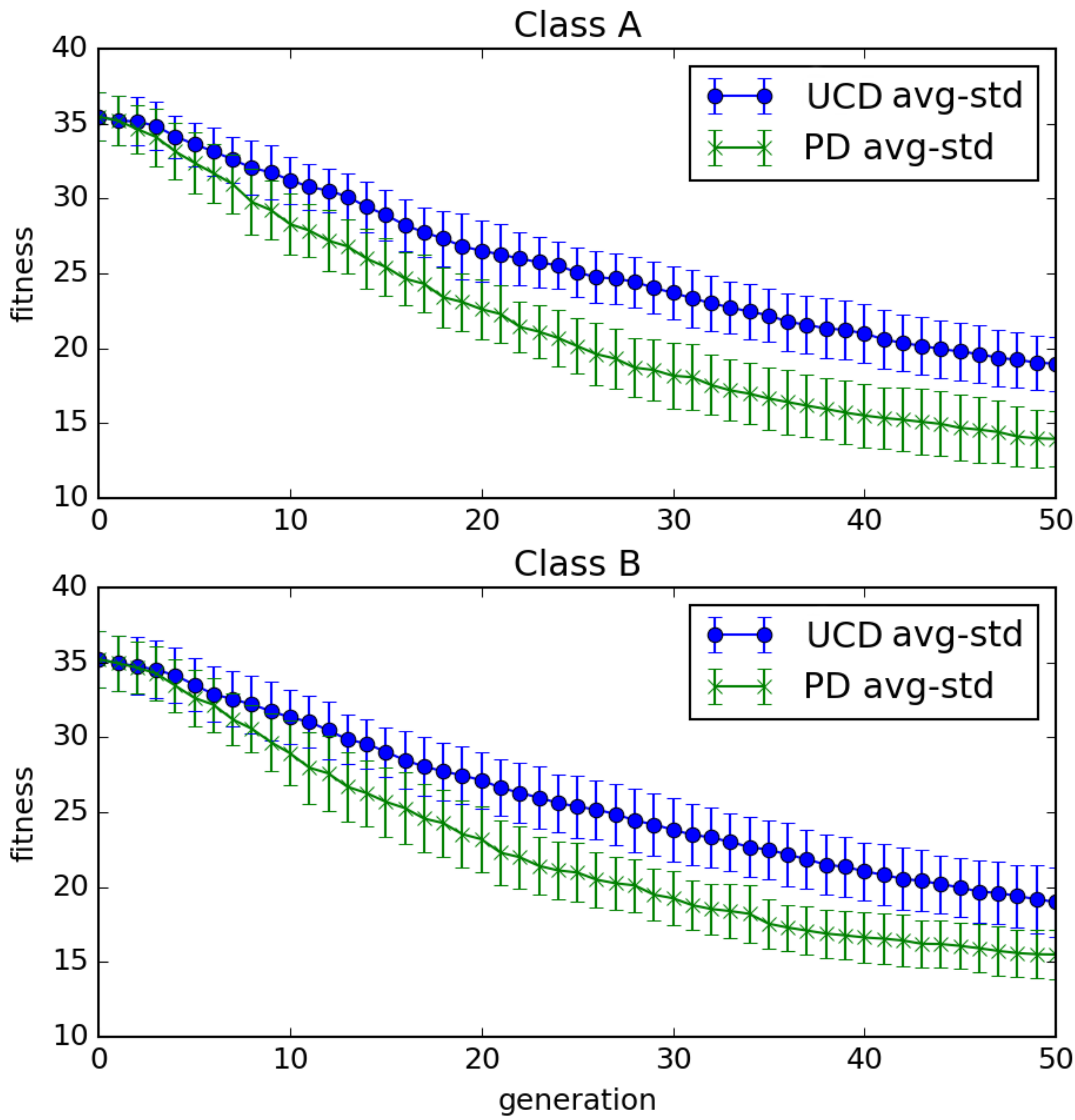


Figure 59. The evolution: namely the fitness function of the best individuals over the generations. Average results of 50 runs.

for class A users is depicted. As already observed PD is always more innovative than UCD. Also in this case, PD performs better than UCD in terms of consensus, however, the absolute values of the fitness function are higher than the ones in the previous experiment. In other words, recalling that we are considering a minimization problem, the fitness of the best individual in this case is slightly worse than the one in the previous experiment. This is somehow consistent with the fact that an higher mutation probability increases the power of randomness, that not necessarily provides better novel solutions. Furthermore, a smaller crossover probability reduces the effects of sex, and consequently the probability of propagating to the offspring the traits of the parents.

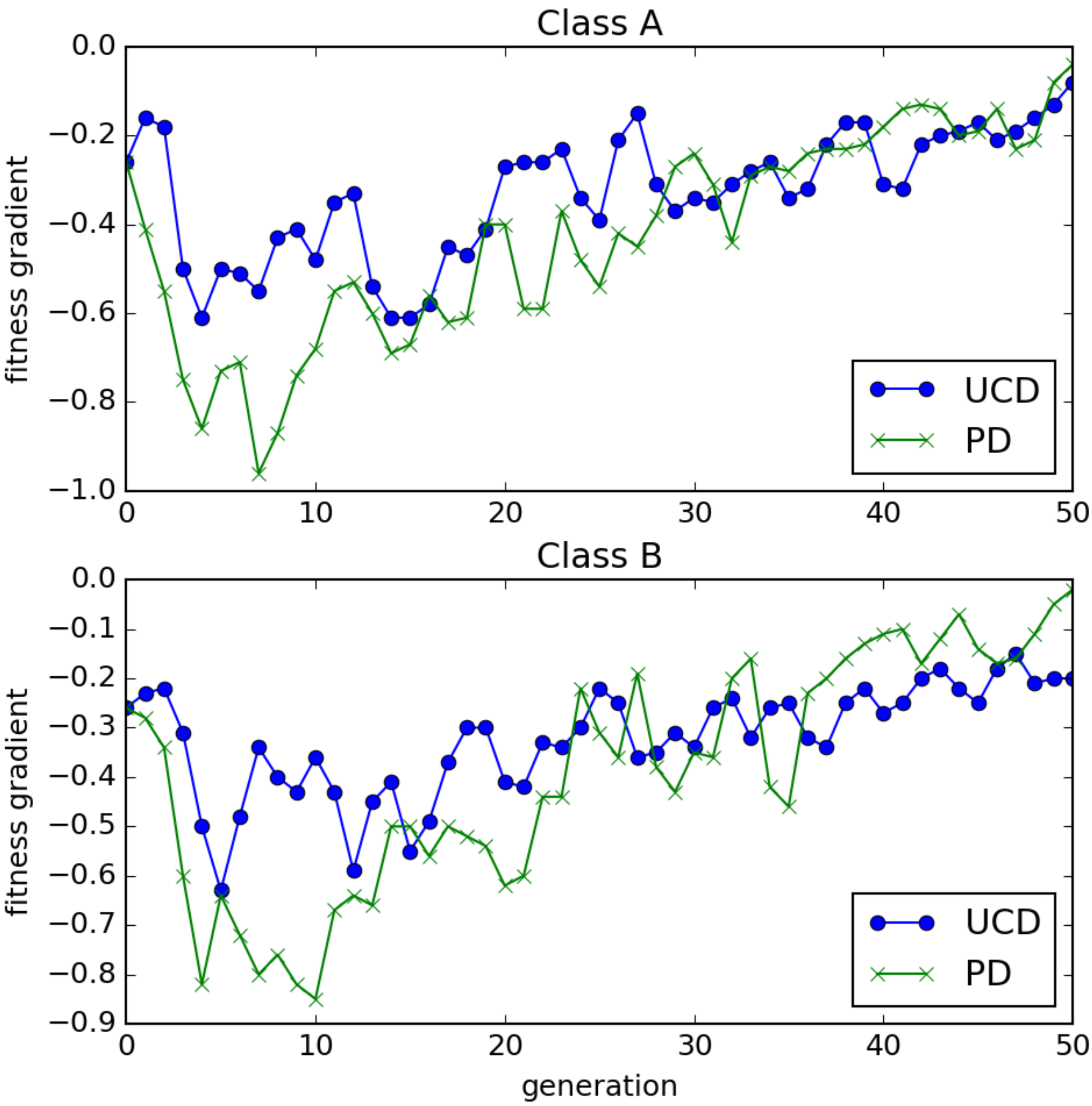


Figure 60. The innovation: the gradient of the evolution over generations.

4 The Visual Analytics Interface

PD raises additional challenges with respect to UCD and among them, as discussed in the previous sections, the consensus among users (see, e.g., [353]), the individual behaviour (see, e.g., [251]), and the social influence (see, e.g., [260]) play a relevant role. The main point is that in PD users have a more active role and stronger opportunity to influence each other; moreover, they want to compare their design solutions against those coming from other users and inspect how much the actual solution differs from their preferences. Such a quantitative and qualitative comparison is an extremely complex task: it requires the evaluation of a number of aspects that are very hard to quantify, such as user tastes and beauty of the outcome. Moreover it requires to inspect and understand the differences in the designs of the diverse users and to relate them to the actual outcomes. To address these tasks, it is mandatory to provide the users with (a) an overview of the available design model and features, (b) a means to modify some of them, and (c) a way to inspect the outcome of the decision process, i.e., the termination of the genetic algorithm, to assess and

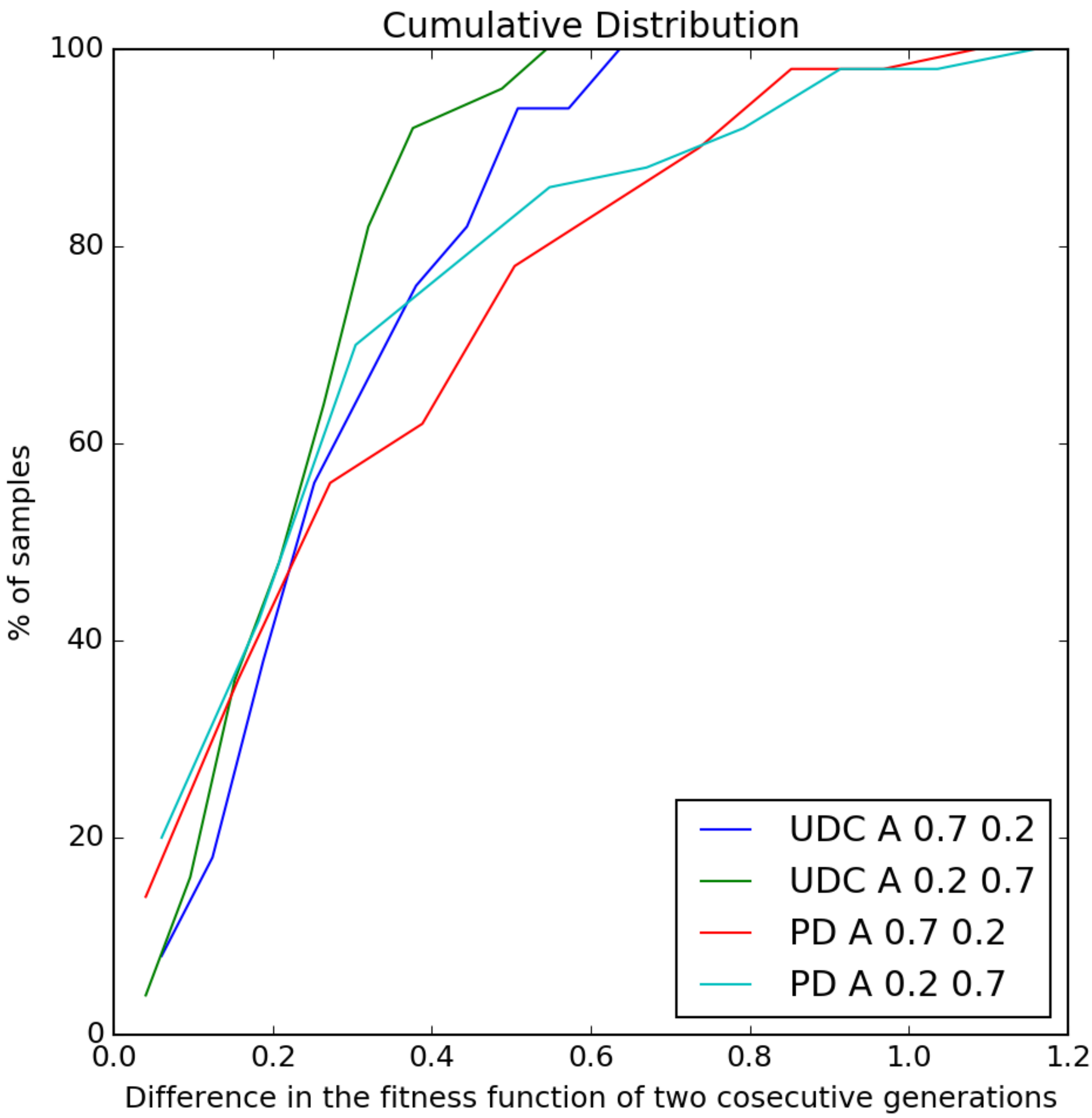


Figure 61. Cumulative distribution of the jumps in the fitness function for class A users when Crossover probability is 0.7 and mutation probability is 0.2 and in the symmetric case.

compare the quality of the actual solutions with their preferences. The complexity of the design and solution spaces suggest for providing the users with a Visual Analytics solution (see, e.g., [187]) and to use space-filling visualizations (see, e.g., [79]) or/and some clutter mitigation techniques (see, e.g., [56] or [124] for a survey).

In this section we introduce a space-filling visualization mockup that has the goal of exemplifying the possible structure and the purposes of the visual analytics interface. Figure 62 shows the 300 individuals (or logos) belonging to the first generation of the genome algorithm described on Section 3. The features considered for the design process are arranged in rows and each column represents the features of a single individual; features are associated with red if they are selected and with blue otherwise. Three users, namely A, B, and C, are designing in a collaborative way a company logo, and the prominent column (individual 20) represents the actual participative contribution of the user C, i.e., the user has selected the corresponding logo as starting point for

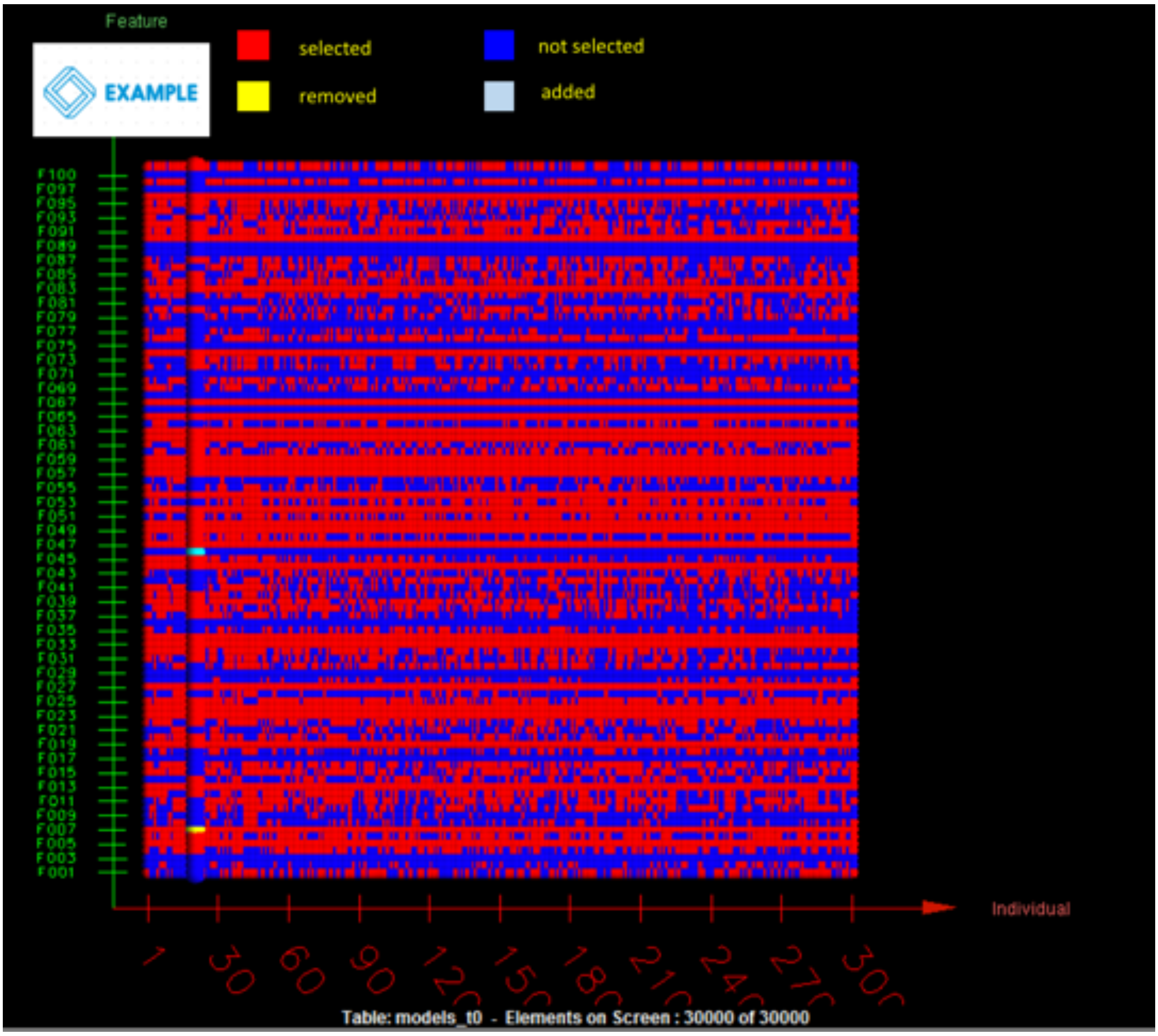


Figure 62. Modifying and comparing individuals' genomes.

her/his design, changing its chromosome in order to address her/his preferences. In particular, user C has deselected the feature F7 (in yellow) and selected the feature F46 (in light blue).

Inspecting the visualization the user can get an understanding of the peculiarity of his proposal with respect to the individuals of the first generation: it is clear that the deselected feature F7 is included in all other individuals, while the selected feature F46 is not included in any individual; moreover, the selection of the uppermost feature F100 is quite popular (mouse hovering on it reveals the number of individuals sharing it: 194 out of 300). On the other hand, user C proposal misses the feature F98 that is instead selected in 225 individuals. Other trends are evident: e.g., the blu lines corresponding to features F75 and F78 show that no individual is including such features. Some possible additional interaction mechanism relies on analytical analysis, e.g., reordering of columns based on the distance (e.g., hamming distance) from the user selection, allowing the inspection of similar solutions; additional coordinated views can provide more details on the selected individual, e.g., the logo corresponding to the actual selection (shown on the top-left of the screen). The modified individual 20 is added to actual population and, together with the modification of users A and B and will contribute to drive the optimization process.

Figure 63 shows the preferences associated to the three users A, B, and C. From the figure it is possible to grasp that user A design is the most demanding in terms of selected features, while users B and C are selecting less features but with different goals: browsing their design space, it is

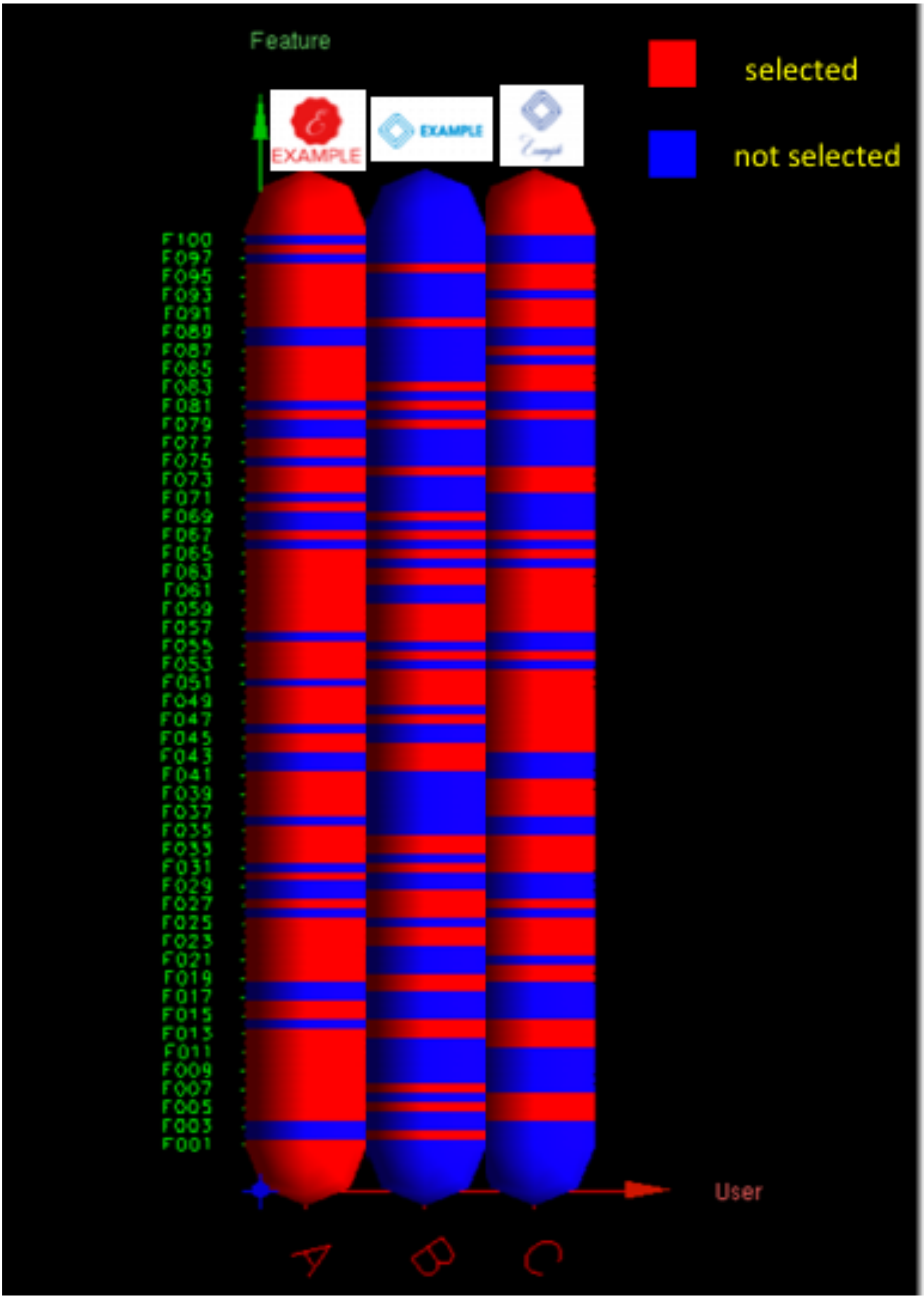


Figure 63. Comparing the preferences of users A, B, and C.

quite common the situation in which they did opp, while in the interval F1-F13 they only agree on the feature F5. It is out the scope of this research to elaborate on how these pieces of information

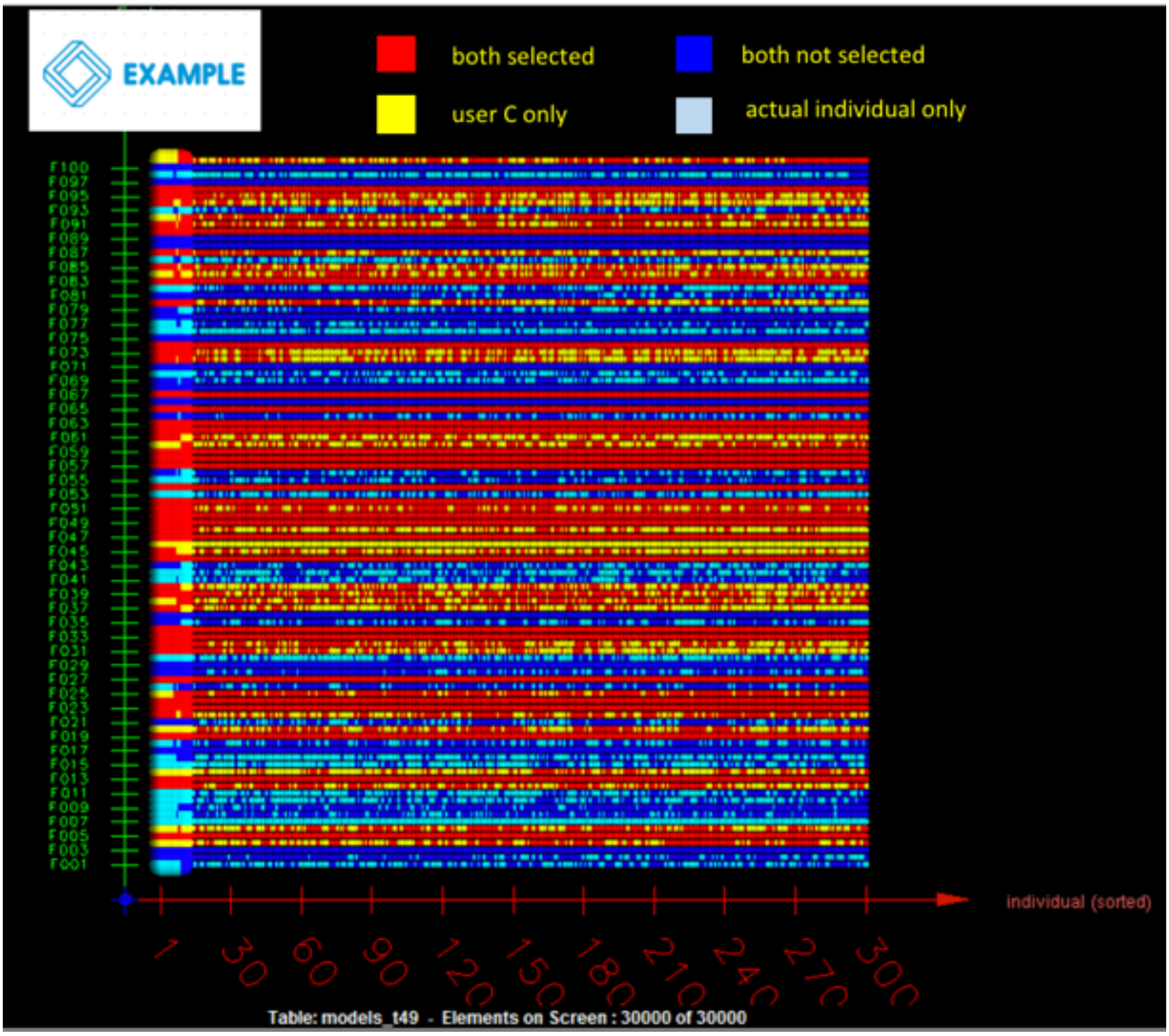


Figure 64. Assessing the quality of the genetic algorithm final population against the user C design.

are related to consensus and social influence; what this section wants to point out is that details about differences and their influence on the final products are a mandatory starting point for such activities.

Figure 64 presents user C with the genetic algorithm final population in which the leftmost individual maximizes the objective functions and the others are ordered from left to right according to their similarity with it (hamming distance). The top10 individuals are magnified to drive the user attention on the best available solutions. Each individual shows the differences with respect to the user C design, according to the following color coding:

- Red represents a feature that exists both in the user C design and the actual individual;
- Blue represents a feature that was not selected both in the user C design and the actual individual;
- Yellow represents a feature that was selected in the user C design but does not appear in the actual individual;
- Light blue represents a feature that was not included in the user C design but appears in the actual individual.

Inspecting the visualization, user C can identify which features are stable with respect to her/his model (red and blue), which ones disappeared (yellow), and which ones have been added (light blue). As an example, the features F72 and F73 are preserved by the optimum (first column) and by the following 6 individuals in the top10; after that the yellow color points out those individuals that do not include that features anymore. The same holds for the features F22 and F39. Moreover, the yellow line corresponding to the feature F46 shows that it is not present in any of the actual individuals, while the feature F7 has been selected in all individuals. While the algorithm is preserving most aspects of user C selection, the unique characteristics of it, the feature F46, disappeared during the optimization process. Also in this visualization it is possible to link a coordinated view to the user selection, showing the corresponding logo and the disappeared features.

It is worth to recall that the mockup shown in this section is just the sketch of one possible solution and, according to user tasks, different visual encodings and visualizations might be more appropriate. The goal here is to make clear the key role that a visual analytics system can play in PD and to provide inspiring examples of the insights the users can get from such a system.

Chapter 7

Conclusions

The conducted work of this thesis concerns research in various industries and contexts like retail and healthcare, which involve multidisciplinary areas and different scenarios. The idea is to explore opportunities and overcome challenges that hamper a successful and comprehensive digital transformation in such industries by shifting the attention from *technology-driven* to *user-driven* service digitalization while carefully considering all the *UX factors* that add to its success. Therefore, the defined research objectives and the related selected case studies of this thesis discuss the important role of applying *service-oriented computing* in **localization**, **clinical guidelines**, and **power-saving** while adopting UCD approaches to achieve the required service digitalization innovation. Besides, other research activities are conducted targeting the application of UCD approaches in advanced topics like **robotics** and investigating how the integration of the unique features of **PD** (Participatory Design) into UCD can lead to innovation in the design process of service digitalization.

On the other hand, some research parts of this thesis involve empirical research work for real industries and companies. When implementing a prototype for such applied research in industry, there are many various perspectives to consider. From one side, there is the business perspective, i.e. marketing and sales of the resulted software, while fulfilling other business requirements. On the other hand, we have to define the scientific research objectives and address them accordingly, while trying to overcome some of the limitations and tackle some of the challenges mentioned in the related state-of-art work. This requires applying the research skills in a way that is focusing on how to fill the gap between academy and industry to achieve successful results for both. Therefore, the research plan of this thesis was defined to accomplish this work by applying UCD approaches to meet real-business industry requirements and derive the output software success.

The rest of the chapter is organized as follows: In Section 1 we introduce a general discussion about the system's main findings, providing a critical analysis of the final results for each research part while investigating the general applicability of the approach. In Section 2, we trace possible directions of future work given the abstract context of user-oriented service digitalization and innovation.

1 Findings, Discussion, and Final Remarks

The research of this thesis is distributed in several case studies related to various industries, contexts, and scenarios to better explore the role of applying human-centered service-oriented computing in leading the promising service digitalization and deriving the required service innovation.

The first research topic investigates a user-centered digitalization of **localization services** to provide a workable cost-effective indoor navigation system for a smart retail environment. The main goal of such a system is to help the retail employees in the scenario of the pick-&-pack order fulfillment. The defined objectives and the adopted methodology show how to realize a complete system implementation targeting a real case study for a real industry. The described steps for analyzing, designing, and implementing the proposed system are carefully considered based on the industry partner requirements and their suggestions. In doing this, UCD approaches and techniques are adopted. One advantage of the proposed system is that it provides a platform-independent front-end solution, which can be rendered into a web layer regardless of the underlying native layer of the used smart mobile device assigned to the navigating employee. Further, the system is developed in such a way that it requires minor modifications to be used for different indoor navigation scenarios in various contexts other than the retail one, which makes the overall solution portable and scalable. After analyzing all the collected results of the performed user study, and verified our hypotheses about the system behavior and usability by analyzing both qualitative and quantitative data using suitable scientific methodologies, we can conclude that the proposed system satisfies a variety of the required *UX features* in this context and answers most of the related defined research questions (as mentioned in section 2.1).

Regarding the second research topic concerning the digitalization of **CGs as services** in healthcare, this thesis presents the main outcomes of the TESTMED project, which aimed at realizing a clinical PAIS supporting doctors during the enactment of CGs in hospital wards, through the interplay of advanced GUIs deployed on mobile devices that provide touch and vocal interaction with the system. The TESTMED system is designed through the UCD methodology [121] and evaluated in a real healthcare environment (i.e., the emergency room of DEA of Policlinico Umberto I, which is the main hospital in Rome (Italy)). This research allowed us to demonstrate that the adoption of mobile devices providing *multimodal GUIs* coupled with a process-oriented execution of clinical tasks represents a valuable solution to support doctors in the execution of CGs, which is validated by the performed user studies. Considering the *UX factors* of working doctors and clinical staff in the design of similar digital healthcare services is a key factor to realize patient-centered clinical operations, and therefore, to unleash service digitalization innovation in smart healthcare spaces.

As for the third research topic concerning the digitalization of automated **power-saving services** in smart spaces, this thesis presents a cost-effective user-centered application with two different architectures; one follows a *Markovian* design and the other follows a *non-Markovian* one. It should be noted that the proposed *non-Markovian* architecture setup (i.e., based on *ultrasonic* and *LIDAR sensors*) does not require using a smart mobile device assigned to the navigating users in the smart space, which works perfectly for the scenario of "*anonymous navigation*" in which the identity of navigators are not considered. On the other hand, utilizing a smart mobile device, which is required in the proposed *Markovian* architecture setup, allows "*authenticated navigation*" that has many advantages to applying privacy rules and ensuring security regulations when accessing the power-saving system of the smart space. Moreover, the mobile can enable several *UX features* (e.g., customizing lighting color, enabling *multimodal interaction* through haptic and vocal interaction and commands, providing information about current zones, etc).

Besides, the *Markovian* architecture setup can face a challenge to detect the correct zone of navigation in the intersecting area between adjacent zones (i.e., the area at the boundary between adjacent zones in which the mobile devices of navigating users may receive very similar *RSSI* readings from the near-by beacons). Although this issue can be addressed carefully at the time of installing beacons given the transmission strength of each beacon unit together with the smart space layout and the corresponding optimized way to divide it into zones, the changing environmental factors or accidental interference with other radio signals can be expected, which would lead to instant misleading *RSSI* readings (i.e., the highest *RSSI* values received may not belong to the closest beacons on the ground, or the values may not be accurate enough to correspondingly calculate the actual distances to the transmitting beacons), and therefore, resulted in many "*false positives*", i.e., wrong detection of the current navigation zone. In this case, the *non-Markovian* design could have a competitive advantage to overcome this challenge by providing a sharp detection at the boundaries between adjacent zones, and therefore, eliminating *false positives* of inaccurate zone detection. This is because good-quality *ultrasonic sensors* can be adjusted to have a very small angle of detection which can be interrupted as a sharp virtual border between adjacent zones. Additionally, *LIDAR sensors* work with an angle-based accuracy (between 0° - 360°) where each angle presents a virtual line-of-sight detection line. Hence, each angle can present a sharp virtual detection border between adjacent zones if considered carefully at the time of installation (i.e., virtual borders between adjacent zones can be mapped to a specific detection angle).

To this end, the concluding remarks from the current results of the implemented system suggest that many factors should be considered altogether when designing similar *power-saving services* in smart spaces from the physical characteristics of the space (e.g., layout) to the *UX factors* of the space users (e.g., their routine and daily patterns while navigating the space, their customized preferences, the nature of the corresponding tasks, etc.)

In the context of investigating *UX factors* in HRI, this thesis addresses the attitude of humans toward collaboration with robots in the social perspective adopted by the so-called *Symbiotic Autonomy*. This specific HRI scenario, where robots ask humans for help, can become a widespread and practical approach and should be given special consideration when designing *RaaS* units, provided that robots exhibit proper social behaviors. In our study on the concept of **Collaboration Attitude** (CA), we found out that CA has indeed not a constant value and depends on different enabling factors. In particular, Proxemics and Gender seem to have a strong influence on the users' attitudes towards collaborating. On the contrary, the environment in which the interaction takes place did not seem to impact on the CA. Hence, we decided to further analyze CA concerning the Activity that users are performing at the moment of the interaction. To this end, we considered two settings, being Standing the case in which users stand at a location or are walking and Sitting when users are sitting in open areas having lunch or studying. We collected data through experimental campaigns, by deploying a robot in real scenarios while interacting with users. An analysis of the collected data shows that users' attitude toward collaboration does not change depending on the activity they are performing. These results are in line with the initial study, where the CA resulted in not being influenced by the Context. The overall study does not allow us to derive obvious guidelines to design robots that take into consideration the context of social interactions. Nevertheless, we believe that a vast plethora of other factors is expected to trigger an impact on the CA of the robot in the context of *Symbiotic Autonomy*, and therefore, on the related required innovation in *RaaS*.

The last topic of this thesis discusses the promising evolution of UCD towards **PD** (Participatory Design) and the related role in delivering service digitalization innovation and success. Undoubtedly, we are in an era in which technology is permeating everybody's life and its "social dimension" is acquiring more and more importance. Nowadays users are at the center of the digital revolution and adapting technology to human nature has always been the key concern of UCD. Nevertheless, UCD lacks the social and participatory component of the user involvement in the design process: users are consulted by designers, test their solutions, but do not co-design such solutions. PD instead gives a different perspective on user participation in the design process, which is oriented towards social innovation, collaborative design and other forms of active involvement of the users. However, while in the ICT field even PD tended along the years to lose its social and collaborative characteristics, basically becoming a variant of UCD, in the *Product Design* field it maintained and even increased such characteristics. Recent works in *Product Design* suggest that large-scale design participation could help to achieve not only sharing but also innovation. On the other hand, drawbacks exist in PD, including the need for dealing with the lack of experience of most of the users-producers and the necessity of motivating them. In this thesis, we provided a constructive contribution that offers a concrete direction to exploit the collaborative features of PD for empowering a UCD project (in line with the recent special issue of the ACM ToCHI journal on "Reimagining Participatory Design" [48]). Specifically, we first surveyed relevant work on PD from both the ICT and *Product Design* perspectives, highlighting its potential to trigger innovation, and then proposed a model and some experiments to support such a claim, in particular in comparison with UCD.

2 Future Work

Concerning the digitalization of **localization services**, we plan to perform another prototyping iteration to enhance the proposed system by adding some more functionalities and possibly assessing more *UX features*. First, we aim to support the real-time navigation process through augmented reality technology, which was not considered in the first prototype respecting the prescribed requirements of the case study as defined by the industry partner (i.e., GK software company in Germany), in which the provided smart mobile devices do not always have a camera to reflect this feature. Moreover, we plan to support map repositioning and reorienting features during the real-time navigation to allow re-centralizing the current position of the navigating user on the map after zooming or rotating the view. Further, we seek to provide *multimodal interaction* with the system (mainly through the smart mobile and its front-end application) by adding a vocal interface to control some functionalities (similar to the TESTMED system in Chapter 3) and possibly providing a vocal assistant (to guide the navigating users vocally), which in turn can provide a better UX while navigation. After preparing a second prototype that implements the suggested functionalities and features, we intend to perform a second user study to check the effectiveness of our approach and system. This experiment can be performed as a controlled experiment whose results can be utilized to validate a good level of usability of the proposed system. The selected tasks of the experiment should be chosen carefully to reflect the cases of the actual system use and reveals its features and characteristics. The measured variables in this experiment will be similar to those of the first study in order to compare the results between the two prototypes while validating the defined hypotheses. Additionally, based on the widely accepted models of the technology acceptance research, we can assess the experiential aspects of our system and explore the interdependencies between its constructs that lead to positive experiences. With these analyses, we can get clear feedback about how the system is meeting the required *UX features* while delivering the defined system requirements.

Regarding the second research topic concerning the digitalization of **CGs as services** in healthcare, we aim to explore the potential of integrating information from embedded IoT medical devices/objects that can be communicated with the clinical mobile technologies to further facilitate the operation of clinical tasks and activities (e.g., to manage patients' monitoring and daily follow-up reports generated from patient-assigned medical devices/sensors that can be communicated as notifications to doctors and other medical staff on their mobiles). Additionally, these collected/generated information, e.g., from distributed medical devices/sensors, can be directly utilized as inputs for related PAIS CGs, which can help to model and run complex CGs efficiently. Following the topic of HRI (in Chapter 5) and the related *RaaS*, we plan to investigate the role of mobile clinical robots (i.e., robots employed in healthcare to cooperate on clinical tasks with doctors and clinical staff). The promising potential to communicate effectively with these robots in the context of smart healthcare space can add a great value to help doctors and medical staff in fulfilling assigned clinical tasks and related activities. As future work, we can also empower the system to support further CGs, such as syncope and dyslipidaemias, to make it usable in more clinical circumstances. Furthermore, we plan to realize a precise methodology that explains how to model CGs as *PROforma* processes. Finally, we plan to test the system for longer periods, enabling just a single interaction modality for doctors (exclusively touch or vocal). This will allow us to understand if the voice interaction feature makes the system more usable and effective than using the traditional touch features of the GUI.

In the context of the digitalization of automated **power-saving services** in smart spaces, we plan to conduct an evaluation user study to compare between the *Markovian* and *non-Markovian* prototypes by measuring several variables including the effectiveness of the system (related to the amount of power consumed), the responsiveness in real-time, the number of detection errors (e.g., *false positives*), etc.

On the other hand, we plan to add other functionalities and features to the system. First, we can impose security rules to implement features like monitoring who navigates the space and where (i.e., in which zone) in real-time. Moreover, we seek to provide *multimodal interaction* with the system (mainly through the smart mobile and its front-end application) by adding a vocal interface to control some functionalities (similar to the TESTMED system in Chapter 3) and possibly providing a vocal assistant (to inform the navigating users vocally about some notifications from the system), which in turn can provide a better UX during navigation. For example, when the system detects the presence of a user in the smart space, it will automatically turn on the lighting unit in the corresponding part of that space. At the same time, the user can control the intensity or color of light directly from their smart mobile device either by using the visual touch interface or simply by giving a vocal command that can be also detected by the vocal interface, which altogether supports the required immersive UX. Enabling the *multimodality* feature would allow users to switch between the different interaction modes (i.e., vocal and haptic) freely as convenient. Additionally, we aim to customize the power-saving system to support various contexts and scenarios (e.g., smart hospitals, smart schools, smart museums, etc). Furthermore, another feature can be added to the system to ensure a better UX by having all empty zones (i.e., without navigating users) dimly lighted (i.e., with low light intensity and brightness) while the zones of navigation will be fully lighted. Other customization possibilities include different colors for each section in the space (i.e., using color code) which can be significant in some scenarios (e.g., assigning color codes for the lighting system in museums to reflect in which part the user is currently navigating).

Another future direction is to integrate the system with other systems, like the localization system mentioned in the first case study in Chapter 2. In such a case, the two services (i.e., localization and power-saving) can work together to provide more customized UX. For example, the lighting system can be used to guide the employee to a specific location within the retail space following the localization data and the destination location. This can be realized by showing the proposed navigation path through space by flashing lights of the corresponding zones along this path alternatively (possibly with a specific color that indicates a navigation path), which can guide the navigating employee until reaching the destination zone. Another example is to illuminate the zone where the searched item (i.e., required destination) is located in a specific color to distinguish it as the destination zone. One more useful example can be related to the scenario of informing employees about items shortage in a specific zone using a specific meaningful color like flashing red light. As discussed, using a color code for lighting can be considered a very useful feature to express several codes for various scenarios. Many other examples can be realized to show how digital *power-saving services* of lighting control can be an added value when integrated with other digital services. It should be noted that this integration should not interfere with other features like customizing lighting color in the space based on the navigating user's preferences. In such a case, the solution can be to limit the customizable lighting color options to those which are not part of the defined color codes (i.e., the system allows the user to select a customization color apart from the defined color codes).

As for the topic of exploring *UX factors* in HRI, and by looking at the collected results from the two performed user studies, we still consider that **Collaboration Attitude** (CA) needs to be better evaluated, possibly including additional elements that will become available to the robot as its perception capabilities improve. Discovering new enabling factors for CA will help increasing robot's chances to be considered a social partner when shaping social behaviors in everyday scenarios spanning from guidance in museums to assistance in shopping malls or hospitals (as mentioned above). Undoubtedly, as soon as robots will operate more frequently in human-populated environments, *Symbiotic Autonomy* will play a key role in achieving a productive coexistence, and thus, humans' collaboration with robots will become essential. To this end, we are planning to investigate how the CA varies between interactions within small groups of people and interactions with individuals, and how participants are influenced by different appearances or structures of the robot. All these factors will contribute to a complete understanding of the characterization of robots' social behaviors, generating a form of bidirectional collaboration with humans. Anticipating and investigating such *UX factors* in HRI while adopting UCD approaches to design and realize the related *RaaS* units should inevitably lead to the required digitalization innovation.

Concerning the last topic of investigating the evolutionary role of **PD** in service digitalization innovation, we gave the first hint on our future work by sketching a visual interface able to let the users analyzing the behavior of their co-designers and the evolution of consensus on certain proposals. The idea here is to study through forthcoming extensive user tests on how the rising of consensus could influence the design choices of the users and how this is related to the emerging of innovations related to digital services design.

Finally, to pursue a promising service digitalization in future work, we seek to better understand the additional evolving factors and principles that contribute to draw its landscape. Moreover, we need to skillfully employ new cutting-edge technologies in service digitalization while adopting advanced UCD approaches to derive the required innovation.

Further, we need to explore the potential brought by understanding the abstract role of **smart services** in line with **smart data** to derive the innovation in **smart products**. In this context, *smart data* can be referred to as the refined data generated by processing the collected raw data from the connected sensors and devices to gain deeper insights using advanced technologies like *Big Data Processing*, *Machine Learning* (ML), and *Artificial Intelligence* (AI). These *smart data* will be then used to implement *smart services* which are data-based digital services that exploit the extracted insights from the *smart data*, and therefore, can communicate and call other services automatically when needed to provide a higher level of smartness. To that extent, the *smart product* can be defined as a product that utilizes various user-oriented *smart services* which, in turn, analyze different sources of the *smart data* generated from the different embedded sensors and devices to autonomously perform complex activities. To understand the hierarchy of *smart data*, *services*, and *products*, we can consider the example of a **smart car**. This proposed smart car can have many *smart services* including the "driving planning" service and the "maintenance" service. Both of these services will use the *smart data* of driving routine by analyzing the accumulated raw data collected from the different sensors (e.g., increasing km mileage, decreasing percentage of oil and water, other electro-mechanical parts readings, trips timing with the corresponding related GPS locations, etc.) during driving. Therefore, when the system detects that the km mileage crossed a specific predefined threshold since the last maintenance check-up schedule or possibly an incident car breakdown occurs in real-time, it can automatically activate the maintenance service. This service, in turn, will possibly communicate with the driving planning service to change the driving route (if the malfunction happens during driving) and redirect it to the closest maintenance station or simply send a notification directly to a preregistered user-selected workshop asking for help and sending the current GPS location. On the other hand, the driving planning service can learn the user's driving habits by inferring the daily (or weekly) driving routine and suggest future routes and trips based on the analyzed history of the collected raw driving data.

Bibliography

[1] Anyplace indoor maps. https://anyplace.cs.ucy.ac.cy/.

[2] Apache cordova, an open-source platform-independent mobile development framework. https://cordova.apache.org/.

[3] Cordova plugin ibeacon link 1. https://ionicframework.com/docs/native/ibeacon/.

[4] Cordova plugin ibeacon link 2. https://github.com/petermetz/cordova-plugin-ibeacon.

[5] Custom mesh indoor maps. https://blog.indoorway.com/mesh-algorithm-for-setting-up-indoor-locations-d3925b01e3d gi=a6d74219ccb1.

[6] Estimote beacons official website. https://estimote.com.

[7] Estimote sdk for indoor map link 1. https://developer.estimote.com/indoor/map-your-location/.

[8] Estimote sdk for indoor map link 2. https://community.estimote.com/hc/en-us/articles/203439046-How-to-set-up-a-location-in-Estimote-Indoor-Location-.

[9] Eu project first official website. https://www.h2020first.eu/.

[10] Gis indoor maps link 1. www.youtube.com/watch?v=DSU0kvXIaPQ.

[11] Gis indoor maps link 2. https://gis.stackexchange.com/questions/29134/seeking-a-gis-for-indoor-mapping-and-direction-finding?rq=1.

[12] Google indoor maps. https://www.google.com/maps/about/partners/indoormaps/.

[13] Google mobile vision barcode scanner website. https://developers.google.com/vision/introduction.

[14] Indooratlas indoor maps. http://www.indooratlas.com/.

[15] Infsoft indoor maps. https://www.infsoft.com/technology/software/sdk.

[16] Ionic framework website. https://ionicframework.com/.

[17] Ionic native scanner framework website. https://ionicframework.com/docs/native/barcode-scanner/.

[18] Ionic plugin for indoor map link 1. https://github.com/petermetz/cordova-plugin-ibeacon.

[19] Ionic plugin for indoor map link 2. https://ionicframework.com/docs/native/ibeacon/.

[20] A live online interactive demo of the in-store navigation proposed prototype. https://xd.adobe.com/view/194aada5-a63e-4a88-5a80-1b93e8830379-6f7b/.

[21] Manatee works barcode scanner license. https://manateeworks.com/uploads/files/Manatee-License-Agreement.pdf/.

[22] Mapsindoors indoor maps. https://www.mapspeople.com/mapsindoors/.

[23] Openstreetmap indoor maps link 1. https://www.openstreetmap.org/#map=6/51.330/10.453.

[24] Openstreetmap indoor maps link 2. https://wiki.openstreetmap.org/wiki/Proposed_features/IndoorOSM#PicLayer.

[25] Openstreetmap indoor maps link 3. https://josm.openstreetmap.de/.

[26] Philips hue official website. https://www2.meethue.com/en-us.

[27] Photoelectric x4 lidar sensor website. https://www.elecrow.com/download/X4_Lidar_Datasheet.pdf.

[28] Quaggajs barcode scanner website. https://github.com/serratus/quaggaJS.

[29] Scandit barcode scanner framework website. https://docs.scandit.com/5.3/android/android-customize-scanui.html.

[30] Scandit barcode scanner license. https://www.scandit.com/de/preise/.

[31] Steerpath indoor maps. https://steerpath.com/.

[32] Ultrasonic distance sensor hy-srf05 website. http://www.pridopia.co.uk/pi-user-manual/A4-ultra-sonic.pdf.

[33] Uugear light sensor module official website. http://www.uugear.com/portfolio/using-light-sensor-module-with-raspberry-pi/.

[34] Zbar barcode scanner website. https://ionicframework.com/docs/native/zbar/.

[35] Zxing barcode scanner framework documentation. https://github.com/zxing/zxing.

[36] An intelligent lightening system for power saving applications. *International Journal of Engineering Trends and Technology (IJETT)*, **13** (2014). Available from: https://pdfs.semanticscholar.org/679d/d3220edd2fa3e8501da4ada185ba1fe8cbab.pdf, doi:https://doi.org/10.1016/j.enbuild.2016.03.041.

[37] Abras, C., Maloney-Krichmar, D., and Preece, J. User-centered design. *Bainbridge, W. Encyclopedia of Human-Computer Interaction. Thousand Oaks: Sage Publications*, **37** (2004), 445.

[38] Alexandrou, D. and Mentzas, G. Research Challenges for Achieving Healthcare Business Process Interoperability. In *International Conference on eHealth, Telemedicine, and Social Medicine*, pp. 58–65 (2009).

[39] Anzbock, R. and Dustdar, S. Semi-automatic generation of Web services and BPEL processes - A Model-Driven approach. In *3rd International Conference on Business Process Management*, pp. 64–79 (2005).

[40] Arleo, A., del R. Millan, J., and Floreano, D. Efficient learning of variable-resolution cognitive maps for autonomous indoor navigation. *IEEE Transactions on Robotics and Automation*, **15** (1999), 990. doi:10.1109/70.817664.

[41] Armstrong, A. and Hagel, J. The real value of online communities. *Knowledge and communities*, **74** (2000), 85.

[42] Artale, A., Calvanese, D., Kontchakov, R., and Zakharyaschev, M. The dl-lite family and relations. *Journal of artificial intelligence research*, **36** (2009), 1.

[43] Augusto, A., Conforti, R., Dumas, M., Rosa, M. L., Maggi, F. M., Marrella, A., Mecella, M., and Soo, A. Automated Discovery of Process Models from Event Logs: Review and Benchmark. *IEEE Transactions on Knowledge and Data Engineering*, (2018). doi:10.1109/TKDE.2018.2841877.

[44] Augusto, J. C., Nakashima, H., and Aghajan, H. Ambient intelligence and smart environments: A state of the art. In *Handbook of ambient intelligence and smart environments*, pp. 3–31. Springer (2010).

[45] B.-N. Sanders, E. From user-centered to participatory design approaches. In *Design and the social sciences: Making connections*, pp. 1–8. CRC Press (2002).

[46] Ba, S., Stallaert, J., and Zhang, Z. Balancing it with the human touch: Optimal investment in it-based customer service. *Information Systems Research*, **21** (2010), 423. doi:10.1287/isre.1100.0282.

[47] Bakeman, R. and Quera, V. *Sequential Analysis and Observational Methods for the Behavioral Sciences*. Cambridge University Press (2011). ISBN 9781139017343. Cambridge Books Online. Available from: http://dx.doi.org/10.1017/CBO9781139017343.

[48] Bannon, L., Bardzell, J., and Bødker, S. Introduction: Reimagining participatory design&;emerging voices. *ACM Trans. Comput.-Hum. Interact.*, **25** (2018), 1:1. Available from: http://doi.acm.org/10.1145/3177794, doi:10.1145/3177794.

[49] Bannon, L., Bardzell, J., and Bodker, S. Reimagining participatory design. *Interactions*, **26** (2018), 26.

[50] Baraglia, J., Cakmak, M., Nagai, Y., Rao, R. P., and Asada, M. Efficient human-robot collaboration. *Int. J. Rob. Res.*, **36** (2017), 563. Available from: https://doi.org/10.1177/0278364916688253, doi:10.1177/0278364916688253.

[51] Barberis, C., Andrea, B., Giovanni, M., and Paolo, M. Experiencing indoor navigation on mobile devices. *IT Professional*, **16** (2014), 50. doi:10.1109/MITP.2013.54.

[52] Bardzell, S. Utopias of participation: Feminism, design, and the futures. *ACM Transactions on Computer-Human Interaction (TOCHI)*, **25** (2018), 6.

[53] Bauer, H. H., Falk, T., and Hammerschmidt, M. etransqual: A transaction process-based approach for capturing service quality in online shopping. *Journal of Business Research*, **59** (2006), 866 . Available from: http://www.sciencedirect.com/science/article/pii/S0148296306000646, doi:https://doi.org/10.1016/j.jbusres.2006.01.021.

[54] Becker, T., Nagel, C., and Kolbe, T. H. *A Multilayered Space-Event Model for Navigation in Indoor Spaces*, pp. 61–77. Springer Berlin Heidelberg, Berlin, Heidelberg (2009). ISBN 978-3-540-87395-2. Available from: https://doi.org/10.1007/978-3-540-87395-2_5, doi:10.1007/978-3-540-87395-2_5.

[55] Belardinelli, F. and Lomuscio, A. Interactions between knowledge and time in a first-order logic for multi-agent systems: completeness results. *Journal of Artificial Intelligence Research*, (2012).

[56] Bertini, E. and Santucci, G. By chance is not enough: Preserving relative density through non uniform sampling. In *Proc. of the International Conference on Information Visualization*, vol. 8 (2004).

[57] Billinghurst, M., Savage, J., Oppenheimer, P., and Edmond, C. The expert surgical assistant. an intelligent virtual environment with multimodal input. *Studies in health technology and informatics*, **29** (1996), 590—607. Available from: http://europepmc.org/abstract/MED/10172851.

[58] Binbin, C., Weimin, H., and Chuping, S. Zigbee technology based central air-conditioning cold source monitoring system and method (2015). Available from: https://patents.google.com/patent/CN104566828A/en.

[59] Bird, J. and Arden, D. Indoor navigation with foot-mounted strapdown inertial navigation and magnetic sensors. *IEEE Wireless Communications*, **18** (2011), 28. doi:10.1109/MWC.2011.5751293.

[60] Bjögvinsson, E., Ehn, P., and Hillgren, P.-A. Design things and design thinking: Contemporary participatory design challenges. *Design Issues*, **28** (2012), 101.

[61] Blanc, G., Mezouar, Y., and Martinet, P. Indoor navigation of a wheeled mobile robot along visual routes. In *Proceedings of the 2005 IEEE International Conference on Robotics and Automation*, pp. 3354–3359 (2005). doi:10.1109/ROBOT.2005.1570628.

[62] Blomberg, J. and Karasti, H. Positioning ethnography within Participatory Design. *Routledge international handbook of participatory design*, (2012), 86.

[63] Bødker, S. Creating conditions for participation: conflicts and resources in systems development. *Human-Computer Interaction*, **11** (1996), 215.

[64] Bødker, S., Bertelsen, O. W., Bannon, L., de Souza, C., Barbosa, S., and Prates, R. *Mediation and Meaning in HCI*, pp. 667–668. Springer International Publishing (2015). ISBN 978-3-319-22723-8. doi:10.1007/978-3-319-22723-8_93.

[65] Bødker, S., Dindler, C., Halskov, K., and Iversen, O. S. Advances in Participatory Design. In *Proc. of the 2016 SIGCHI Conference on Human Factors in Computing Systems (CHI '16) - Extended Abstracts*, pp. 984–987. ACM (2016). ISBN 978-1-4503-4082-3. Available from: http://doi.acm.org/10.1145/2851581.2856688, doi:10.1145/2851581.2856688.

[66] Bødker, S. and Kyng, M. Participatory design that mattersFacing the big issues. *ACM Transactions on Computer-Human Interaction (TOCHI)*, **25** (2018), 4.

[67] Bongartz, S., Jin, Y., Paternò, F., Rett, J., Santoro, C., and Spano, L. D. Adaptive user interfaces for smart environments with the support of model-based languages. In *International Joint Conference on Ambient Intelligence*, pp. 33–48. Springer (2012).

[68] Booth, N., Robinson, P., and Kohannejad, J. Identification of high-quality consultation practice in primary care: the effects of computer use on doctor–patient rapport. *Informatics in primary care*, **12** (2004), 75.

[69] Boussard, M., Christophe, B., Le Berre, O., and Toubiana, V. Providing user support in web-of-things enabled smart spaces. In *Proceedings of the Second International Workshop on Web of Things*, p. 11. ACM (2011).

[70] Boyer, K., Hallowell, R., and V. Roth, A. E-services operating strategy?a case study and method for analyzing operational benefits. *Journal of Operations Management*, **20** (2002), 175. doi:10.1016/S0272-6963(01)00093-6.

[71] Brereton, M. and Buur, J. New challenges for design participation in the era of ubiquitous computing. *Co-Design*, **4** (2008).

[72] Brown, T. *Change by design*. HarperCollins Press (2009).

[73] Buntin, M. B., Burke, M. F., Hoaglin, M. C., and Blumenthal, D. The benefits of health information technology: a review of the recent literature shows predominantly positive results. *Health affairs*, **30** (2011), 464.

[74] Butz, A., Baus, J., Krüger, A., and Lohse, M. A hybrid indoor navigation system. In *Proceedings of the 6th International Conference on Intelligent User Interfaces*, IUI '01, pp. 25–32. ACM, New York, NY, USA (2001). ISBN 1-58113-325-1. Available from: http://doi.acm.org/10.1145/359784.359832, doi:10.1145/359784.359832.

[75] Byun, J. and Park, S. Development of a self-adapting intelligent system for building energy saving and context-aware smart services. *IEEE Transactions on Consumer Electronics*, **57** (2011), 90. doi:10.1109/TCE.2011.5735486.

[76] Byun, J. and Shin, T. Design and implementation of an energy-saving lighting control system considering user satisfaction. *IEEE Transactions on Consumer Electronics*, **64** (2018), 61. doi:10.1109/TCE.2018.2812061.

[77] Calvanese, D., De Giacomo, G., Lenzerini, M., Nardi, D., and Rosati, R. Description logic framework for information integration. In *Proc. of the 6th Int. Conf. on the Principles of Knowledge Representation and Reasoning (KR'98)*, pp. 2–13 (1998).

[78] Capata, A., Marella, A., and Russo, R. A geo-based application for the management of mobile actors during crisis situations. In *Proceedings of the 5th International ISCRAM Conference, Washington, DC* (2008).

[79] Card, S. K. and Mackinlay, J. The structure of the information visualization design space. In *Information Visualization, 1997. Proceedings., IEEE Symposium on*, pp. 92–99. IEEE (1997).

[80] Caroni, C. and Karioti, V. Detecting an innovative outlier in a set of time series. *Computational Statistics and Data Analysis*, **46** (2004), 561.

[81] Carreras, A., Morenza-Cinos, M., Pous, R., Melià-Seguí, J., Nur, K., Oliver, J., and De Porrata-Doria, R. Store view: Pervasive rfid & indoor navigation based retail inventory management. In *Proceedings of the 2013 ACM Conference on Pervasive and Ubiquitous Computing Adjunct Publication*, UbiComp '13 Adjunct, pp. 1037–1042. ACM, New York, NY, USA (2013). ISBN 978-1-4503-2215-7. Available from: http://doi.acm.org/10.1145/2494091.2496011, doi:10.1145/2494091.2496011.

[82] Castells, M. The internet galaxy: reflection on the internet. *Business, and Society. Oxford University Press*, (2001), 292.

[83] Catarci, T., Leotta, F., Humayoun, S. R., Marrella, A., Poggi, A., Kimani, S., and Mecella, M. Horizon: A development methodology for collaborative projects. Tech. rep., Department of Computer, Control and Management Engineering "A. Ruberti", Sapienza - Universitá degli Studi di Roma (2015).

[84] Catarci, T., Leotta, F., Marrella, A., Mecella, M., and Sharf, M. Process-aware enactment of clinical guidelines through multimodal interfaces. *Computers*, **8** (2019). Available from: https://doi.org/10.3390/computers8030067.

[85] Chang, I., Tiao, G. C., and Chen, C. Estimation of time series parameters in the presence of outliers. *Technometrics*, **30** (1988), 193. doi:10.1080/00401706.1988.10488367.

[86] Chatterjee, S., Chakraborty, S., Sarker, S., Sarker, S., and Lau, F. Y. Examining the success factors for mobile work in healthcare: A deductive study. *Decision Support Systems*, **46** (2009), 620.

[87] Chaudhry, B., Wang, J., Wu, S., Maglione, M., Mojica, W., Roth, E., Morton, S. C., and Shekelle, P. G. Systematic review: impact of health information technology on quality, efficiency, and costs of medical care. *Annals of internal medicine*, **144** (2006), 742.

[88] Chea, S. and Luo, M. Post-adoption behaviors of e-service customers: The interplay of cognition and emotion. *Int. J. Electron. Commerce*, **12** (2008), 29. Available from: http://dx.doi.org/10.2753/JEC1086-4415120303, doi:10.2753/JEC1086-4415120303.

[89] Chew, I., Kalavally, V., Oo, N. W., and Parkkinen, J. Design of an energy-saving controller for an intelligent led lighting system. *Energy and Buildings*, **120** (2016), 1 . Available from: http://www.sciencedirect.com/science/article/pii/S0378778816301955, doi:https://doi.org/10.1016/j.enbuild.2016.03.041.

[90] Chris, A. Makers: The New Industrial Revolution. *New York: Crown Business*, (2012).

[91] Chunyu Liu, Quangen Wang, and Fangyuan Zhang. Design and development of city street-lighting energy-saving system. In *2010 Second Pacific-Asia Conference on Circuits, Communications and System*, vol. 1, pp. 178–182 (2010). doi:10.1109/PACCS.2010.5627060.

[92] Clune, J. and Lipson, H. Evolving three-dimensional objects with a generative encoding inspired by developmental biology. In *ECAL* (2011).

[93] Cohen, P. R., Johnston, M., McGee, D., Oviatt, S., Pittman, J., Smith, I., Chen, L., and Clow, J. Quickset: Multimodal interaction for distributed applications. In *Proceedings of the Fifth ACM International Conference on Multimedia*, MULTIMEDIA '97, pp. 31–40. ACM, New York, NY, USA (1997). ISBN 0-89791-991-2. Available from: http://doi.acm.org/10.1145/266180.266328, doi:10.1145/266180.266328.

[94] Cohn, J. F., Kruez, T. S., Matthews, I., Yang, Y., Nguyen, M. H., Padilla, M. T., Zhou, F., and la Torre, F. D. Detecting depression from facial actions and vocal prosody. In *2009 3rd International Conference on Affective Computing and Intelligent Interaction and Workshops*, pp. 1–7 (2009).

[95] Collerton, T., Marrella, A., Mecella, M., and Catarci, T. Route recommendations to business travelers exploiting crowd-sourced data. In *International Conference on Mobile Web and Information Systems*, pp. 3–17. Springer (2017).

[96] Collier, J. and Bienstock, C. Measuring service quality in e-retailing. *Journal of Service Research*, **8** (2006), 260. doi:10.1177/1094670505278867.

[97] Cook, R. and Foster, J. The impact of Health Information Technology (I-HIT) Scale: the Australian results. In *Nursing Informatics*, pp. 400–404 (2009).

[98] Coopers, Price Waterhouse Light Research Institute. Healthcare unwired: New business models delivering care anywhere. (2010).

[99] Coradeschi, S. and Saffiotti, A. Symbiotic robotic systems: Humans, robots, and smart environments. *IEEE Intelligent Systems*, **21** (2006), 82. doi:10.1109/MIS.2006.59.

[100] Cruickshank, M. L. *Open Design and Innovation: facilitating creativity in everyone.* Gower Publishing, Ltd. (2014).

[101] Czerny, B. J., D'Ambrosio, J., and Debouk, R. Iso 26262 functional safety draft international standard for road vehicles: Background, status, and overview. *Communication material*, (2015).

[102] Dadam, P., Reichert, M., and Kuhn, K. Clinical workflows—the killer application for process-oriented information systems? In *BIS 2000*, pp. 36–59. Springer (2000).

[103] de Clercq, P. A., Blom, J. A., Korsten, H. H., and Hasman, A. Approaches for creating computer-interpretable guidelines that facilitate decision support. *Artificial intelligence in medicine*, **31** (2004).

[104] De Giacomo, G., Maggi, F. M., Marrella, A., and Patrizi, F. On the Disruptive Effectiveness of Automated Planning for LTL*f*-Based Trace Alignment. In *Proceedings of the Thirty-First AAAI Conference on Artificial Intelligence, February 4-9, 2017, San Francisco, California, USA*, pp. 3555–3561 (2017).

[105] De Giacomo, G., Maggi, F. M., Marrella, A., and Sardiña, S. Computing Trace Alignment against Declarative Process Models through Planning. In *Proceedings of the Twenty-Sixth International Conference on Automated Planning and Scheduling, ICAPS 2016, London, UK, June 12-17, 2016*, pp. 367–375 (2016).

[106] de Graaf, M. M. and Ben Allouch, S. Expectation setting and personality attribution in hri. In *Proceedings of the 2014 ACM/IEEE International Conference on Human-robot Interaction*, HRI '14, pp. 144–145. ACM, New York, NY, USA (2014). ISBN 978-1-4503-2658-2. Available from: http://doi.acm.org/10.1145/2559636.2559796, doi:10.1145/2559636.2559796.

[107] de Leoni, M., Lanciano, G., and Marrella, A. Aligning Partially-Ordered Process-Execution Traces and Models Using Automated Planning. In *Proceedings of the Twenty-Eight International Conference on Automated Planning and Scheduling (ICAPS 2018)*, pp. 321–329 (2018). ISBN 978-1-57735-797-1. Available from: https://aaai.org/ocs/index.php/ICAPS/ICAPS18/paper/view/17739/16951.

[108] de Leoni, M. and Marrella, A. Aligning Real Process Executions and Prescriptive Process Models through Automated Planning. *Expert Syst. Appl.*, **82** (2017), 162. doi:10.1016/j.eswa.2017.03.047.

[109] de Leoni, M., Marrella, A., and Russo, A. Process-aware information systems for emergency management. In *European Conference on a Service-Based Internet*, pp. 50–58. Springer (2010).

[110] De Mul, J. Redesigning design. *Open Design Now: Why Design Cannot Remain Exclusive. Amsterdam: BIS publishers*, (2011).

[111] de Souza, S. B., da Silva, M. M. A. S., Rodrigues, R. P., Malta, M. E. B., de Gusmao, C. M. G., and dos Santos, W. P. PlantasMED: A mobile application to promote the rational use of medicinal plants in Brazil countryside based on participatory HCI design and popular education for health. In *2014 IEEE 3nd International Conference on Serious Games and Applications for Health (SeGAH)*, pp. 1–8 (2014). doi:10.1109/SeGAH.2014.7067081.

[112] de Ven, A. H. V. and Huber, G. P. Longitudinal field research methods for studying processes of organizational change. *Organization Science*, **1** (1990), 213. Available from: http://www.jstor.org/stable/2635003.

[113] de Ven, A. H. V. and Poole, M. S. Alternative approaches for studying organizational change. *Organization Studies*, **26** (2005), 1377. Available from: https://doi.org/10.1177/0170840605056907, arXiv:https://doi.org/10.1177/0170840605056907, doi:10.1177/0170840605056907.

[114] Del Aguila-Obra, A. R., Padilla-Meléndez, A., and Al-dweeri, R. The influence of electronic service quality on loyalty in postal services: The mediating role of satisfaction. *Total Quality Management & Business Excellence*, **24** (2013). doi:10.1080/14783363.2013.807681.

[115] Devi, D., Kumar, A., Scholar, P., and Tech, M. Design and implementation of cpld based solar power saving system for street lights and automatic traffic controller (2018). doi:10.13140/RG.2.2.11523.60963.

[116] Di Ciccio, C., Marrella, A., and Russo, A. Knowledge-Intensive Processes: Characteristics, Requirements and Analysis of Contemporary Approaches. *Journal on Data Semantics*, **4** (2015), 29. Available from: https://doi.org/10.1007/s13740-014-0038-4, doi:10.1007/s13740-014-0038-4.

[117] Diaper, D. and Stanton, N. *The Handbook of Task Analysis for Human-Computer Interaction*. Lawrence Erlbaum, Mahwah, NJ (2004). ISBN 1410609405 9781410609403 0805844325 9780805844320.

[118] D'Ignazio, C., Hope, A., Michelson, B., Churchill, R., and Zuckerman, E. A Feminist HCI Approach to Designing Postpartum Technologies: "When I first saw a breast pump I was wondering if it was a joke". In *Proc. of the 2016 SIGCHI Conference on Human Factors in Computing Systems (CHI '16)*, pp. 2612–2622. ACM (2016).

[119] DiSalvo, B. Participatory Design Through a Learning Science Lens. In *Proc. of the 2016 SIGCHI Conference on Human Factors in Computing Systems (CHI '16)*, pp. 4459–4463. ACM (2016). ISBN 978-1-4503-3362-7. Available from: http://doi.acm.org/10.1145/2858036.2858405, doi:10.1145/2858036.2858405.

[120] DiSalvo, C., Maki, J., and Martin, N. Mapmover: a case study of design-oriented research into collective expression and constructed publics. In *Proc. of the 2007 SIGCHI conference on Human Factors in Computing Systems (CHI '07)*, pp. 1249–1252. ACM (2007).

[121] Dix, A., Finlay, J., Abowd, G., and Beale, R. *Human-computer Interaction*. Prentice-Hall, Inc., Upper Saddle River, NJ, USA (1997). ISBN 0-13-437211-5.

[122] Dix, A., Finlay, J., Abowd, G., and Beale, R. *Human-Computer Interaction*. Pearson, 3rd edn. (2009).

[123] Duarte, A. M. B., Brendel, N., Degbelo, A., and Kray, C. Participatory design and participatory research: an HCI case study with young forced migrants. *ACM Transactions on Computer-Human Interaction (TOCHI)*, **25** (2018), 3.

[124] Ellis, G. and Dix, A. A taxonomy of clutter reduction for information visualisation. *IEEE Transactions on Visualization and Computer Graphics*, **13** (2007), 1216. doi:10.1109/TVCG.2007.70535.

[125] Elsagheer Mohamed, S. Smart street lighting control and monitoring system for electrical power saving by using vanet. *Int'l J. of Communications, Network and System Sciences*, **06** (2013), 351. doi:10.4236/ijcns.2013.68038.

[126] Endsley, M. R. *Designing for Situation Awareness: An Approach to User-Centered Design*. CRC press (2016).

[127] Engel, C. Dictator games: a meta study. *Max Planck Institute for Research on Collective Goods, Working Paper Series of the Max Planck Institute for Research on Collective Goods*, **14** (2010). doi:10.2139/ssrn.1568732.

[128] Fahland, D. and van der Aalst, W. M. Repairing process models to reflect reality. In *International Conference on Business Process Management*, pp. 229–245. Springer (2012).

[129] Field, M. J. and Lohr, K. N. *Clinical Practice Guidelines: Directions for a New Program*. Institute of Medicine, Washington, DC (1990).

[130] Fischer, G. Beyond 'Couch Potatoes': From Consumers to Designers and Active Contributors. *Firstmonday (Peer-Reviewed Journal on the Internet)*, (2002).

[131] Fischer, G. End-user development and meta-design: Foundations for cultures of participation. In *End-User Computing, Development, and Software Engineering: New Challenges*. IGI Global (2012).

[132] Fischer, G. and Giaccardi, E. Meta-design: A framework for the future of end-user development. In *End user development*. Springer (2006).

[133] Fischer, K., Yang, S., Mok, B., Maheshwari, R., Sirkin, D., and Ju, W. Initiating interactions and negotiating approach: A robotic trash can in the field (2015). Available from: https://www.aaai.org/ocs/index.php/SSS/SSS15/paper/view/10244.

[134] Fleury, A., Vacher, M., and Noury, N. Svm-based multimodal classification of activities of daily living in health smart homes: Sensors, algorithms, and first experimental results. *IEEE Transactions on Information Technology in Biomedicine*, **14** (2010), 274. doi:10.1109/TITB.2009.2037317.

[135] Flood, D., Germanakos, P., Harrison, R., McCaffery, F., and Samaras, G. Estimating cognitive overload in mobile applications for decision support within the medical domain. In *ICEIS 2012 - Proceedings of the 14th International Conference on Enterprise Information Systems, Volume 3, Wroclaw, Poland, 28 June - 1 July, 2012*, pp. 103–107 (2012).

[136] Fortin, F.-A., De Rainville, F.-M., Gardner, M.-A., Parizeau, M., and Gagné, C. DEAP: Evolutionary algorithms made easy. *Journal of Machine Learning Research*, **13** (2012), 2171.

[137] Fox, A. J. Outliers in time series. *Journal of the Royal Statistical Society, Series B: Methodological*, **34** (1972), 350.

[138] Frauenberger, C., Good, J., Fitzpatrick, G., and Iversen, O. S. In pursuit of rigour and accountability in participatory design. *International Journal of Human-Computer Studies*, **74** (2015), 93 . Available from: http://www.sciencedirect.com/science/article/pii/S1071581914001232, doi:http://dx.doi.org/10.1016/j.ijhcs.2014.09.004.

[139] Gandhi, P., Khanna, S., and Ramaswamy, S. Which industries are the most digital (and why? *Harvard Business Review*, (2016).

[140] Gershenfeld, N. *Fab: the coming revolution on your desktop–from personal computers to personal fabrication*. Basic Books (2008).

[141] Gimpel, H. and Röglinger, M. Digital transformation : Changes and chances ? insights based on an empirical study (2015).

[142] Golding, A. and Lesh, N. Indoor navigation with wearable passive sensors (2001). US Patent 6,323,807. Available from: https://www.google.tl/patents/US6323807.

[143] Golding, A. R. and Lesh, N. Indoor navigation using a diverse set of cheap, wearable sensors. In *Digest of Papers. Third International Symposium on Wearable Computers*, pp. 29–36 (1999). doi:10.1109/ISWC.1999.806640.

[144] Gooch, D., et al. Amplifying quiet voices: Challenges and opportunities for participatory design at an urban scale. *ACM Transactions on Computer-Human Interaction (TOCHI)*, **25** (2018), 2.

[145] Gozick, B., Subbu, K. P., Dantu, R., and Maeshiro, T. Magnetic maps for indoor navigation. *IEEE Transactions on Instrumentation and Measurement*, **60** (2011), 3883. doi:10.1109/TIM.2011.2147690.

[146] Grace, K., Maher, M. L., Preece, J., Yeh, T., Stangle, A., and Boston, C. A process model for crowdsourcing design: a case study in citizen science. In *Design Computing and Cognition'14*. Springer (2015).

[147] Guerrieri, J. R., Francis, M. H., Wilson, P. F., Kos, T., Miller, L. E., Bryner, N. P., Stroup, D. W., and Klein-Berndt, L. Rfid-assisted indoor localization and communication for first responders. In *2006 First European Conference on Antennas and Propagation*, pp. 1–6 (2006). doi:10.1109/EUCAP.2006.4584714.

[148] Gupta, D. and Denton, B. Appointment scheduling in health care: Challenges and opportunities. *IIE transactions*, **40** (2008), 800.

[149] Haertfelder, J. and Winkelmann, A. Opportunities and challenges for local retailing in an environment dominated by mobile internet devices – literature review and gap analysis. *not defined*, (2016).

[150] Hall, E. T. E. T. *The hidden dimension : man's use of space in public and private*. London : Bodley Head (1966).

[151] Han, D., Jung, S., Lee, M., and Yoon, G. Building a practical wi-fi-based indoor navigation system. *Pervasive Computing, IEEE*, **13** (2014), 72.

[152] Hansen, T., Eklund, J., Sprinkle, J., Bajcsy, R., and Sastry, S. Using smart sensors and a camera phone to detect and verify the fall of elderly persons. In *3rd European Medicine, Biology and Engineering Conference* (2005).

[153] Hassenzahl, M. User experience (ux): towards an experiential perspective on product quality. In *Proceedings of the 20th Conference on l'Interaction Homme-Machine*, pp. 11–15. ACM (2008).

[154] Hedin, J. and Meier, B. Voice control of a user interface to service applications (2001). US Patent 6,185,535. Available from: http://www.google.com/patents/US6185535.

[155] Hess, J. and Pipek, V. Community-Driven Development: Approaching Participatory Design in the Online World. *Design Issues*, **28** (2012), 62.

[156] Ho, C.-I. and Lee, Y.-L. The development of an e-travel service quality scale. *Tourism Management*, **28** (2007), 1434. doi:10.1016/j.tourman.2006.12.002.

[157] Huang, H. and Gartner, G. *A Survey of Mobile Indoor Navigation Systems*, pp. 305–319. Springer Berlin Heidelberg, Berlin, Heidelberg (2010). ISBN 978-3-642-03294-3. Available from: https://doi.org/10.1007/978-3-642-03294-3_20, doi:10.1007/978-3-642-03294-3_20.

[158] Huang, J., Yang, Y. C., Zhai, X. D., and Yang, C. The design of smart home monitoring system based on zigbee and voice recognition technology. In *Advances in Manufacturing Science and Engineering V*, vol. 945 of *Advanced Materials Research*, pp. 2693–2697. Trans Tech Publications Ltd (2014). doi:10.4028/www.scientific.net/AMR.945-949.2693.

[159] Huang, M.-H. and T. Rust, R. It-related service a multidisciplinary perspective. *Journal of Service Research*, **16** (2013), 251. doi:10.1177/1094670513481853.

[160] Humayoun, S. R., Catarci, T., de Leoni, M., Marrella, A., Mecella, M., Bortenschlager, M., and Steinmann, R. The WORKPAD User Interface and Methodology: Developing Smart and Effective Mobile Applications for Emergency Operators. In *Universal Access in Human-Computer Interaction. Applications and Services*, pp. 343–352. Springer Berlin Heidelberg (2009). ISBN 978-3-642-02713-0.

[161] Humayoun, S. R., Dubinsky, Y., and Catarci, T. A Three-Fold Integration Framework to Incorporate User-Centered Design into Agile Software Development. In *Proc. of International Conference on Human Centered Design (HCD 2011)*, pp. 55–64. Springer (2011).

[162] Humayoun, S. R., Sharf, M., AlTarawneh, R., Ebert, A., and Catarci, T. Vizcom: Viewing, zooming and commenting through mobile devices. In *Proceedings of the 2015 International Conference on Interactive Tabletops & Surfaces*, ITS '15, pp. 331–336. ACM, New York, NY, USA (2015). ISBN 978-1-4503-3899-8. Available from: http://doi.acm.org/10.1145/2817721.2823502, doi:10.1145/2817721.2823502.

[163] Imbesi, L. DESIGN POWER. Design cognitariat at work in the organization of the knowledge capital. *Design Thinking: New Challenges for Designers, Managers and Organizations*, (2008).

[164] Imbesi, L. Copy & Paste: Design in the Era of Postproduction. In *Proc. of the Third Int. Conf. on Design Principles and Practices*. Common Ground (2009).

[165] Imbesi, L. Design comes out of industry: new critical approaches for design in the economy of post-production. Tech. rep., Cumulus working papers 27/11 Paris-Sèvres. Publication series G (2012).

[166] Imre, M., Oztop, E., Nagai, Y., and Ugur, E. Affordance-based altruistic robotic architecture for human?robot collaboration. *Adaptive Behavior*, **27** (2019), 223. Available from: https://doi.org/10.1177/1059712318824697, arXiv:https://doi.org/10.1177/1059712318824697, doi:10.1177/1059712318824697.

[167] Inoue, Y., Sashima, A., Ikeda, T., and Kurumatani, K. Indoor emergency evacuation service on autonomous navigation system using mobile phone. In *2008 Second International Symposium on Universal Communication*, pp. 79–85 (2008). doi:10.1109/ISUC.2008.49.

[168] Isern, D. and Moreno, A. Computer-based execution of clinical guidelines: a review. *International journal of medical informatics*, **77** (2008), 787.

[169] Iyengar, M., Carruth, T., Florez-Arango, J., and Dunn, K. Informatics-based medical procedure assistance during space missions. *Hippokratia*, **12** (2008), 23.

[170] Iyengar, M. S., Florez-Arango, J. F., and Garcia, C. A. GuideView: a system for developing structured, multimodal, multi-platform persuasive applications. In *Proceedings of the 4th International Conference on Persuasive Technology*. ACM (2009).

[171] Jaber, R. N., AlTarawneh, R., and Humayoun, S. R. Characterizing pairs collaboration in a mobile-equipped shared-wall display supported collaborative setup. *CoRR*, **abs/1904.13364** (2019). Available from: http://arxiv.org/abs/1904.13364, arXiv:1904.13364.

[172] Jakobsen, M. R. and HornbAEk, K. Up close and personal: Collaborative work on a high-resolution multitouch wall display. *ACM Trans. Comput.-Hum. Interact.*, **21** (2014), 11:1. Available from: http://doi.acm.org/10.1145/2576099, doi:10.1145/2576099.

[173] Jayaram, A. Smart retail 4.0 iot consumer retailer model for retail intelligence and strategic marketing of in-store products. *not defined*, (2017).

[174] Jones, J. C. *Design methods: seeds of human futures*. John Wiley & Sons (1992).

[175] Jourde, F., Laurillau, Y., Moran, A., and Nigay, L. Towards specifying multimodal collaborative user interfaces: A comparison of collaboration notations. In *Interactive Systems. Design, Specification, and Verification*, pp. 281–286. Springer (2008).

[176] Jun, Y. and Yongzhong, X. Design of analog road lighting power-saving control system (2010). Available from: http://en.cnki.com.cn/Article_en/CJFDTotal-ZMGX201002014.htm.

[177] Kadir, K. M., Forhad, M. S., Fadlullah, M. M., Quader, N., Al-Arif, M. M. R., and Dhali, M. A. Energy saving by automatic control of power in simple home appliances. In *2011 IEEE 3rd International Conference on Communication Software and Networks*, pp. 311–315 (2011). doi:10.1109/ICCSN.2011.6014058.

[178] Kathuria, A., Khuntia, J., and Saldanha, T. Digital service flexibility: A theory in the context of service firms (2013).

[179] Kathuria, A., Rojas, M., Saldanha, T., and Khuntia, J. Extent versus range of service digitization: Implications for firm performance (2014).

[180] Kee, C., Yun, D., Jun, H., Parkinson, B., Pullen, S., and T. Centimeter-accuracy indoor navigation using gps-like pseudolites. *GPS WORLD*, (2001).

[181] Kell, D. B. and Lurie-Luke, E. The virtue of innovation: innovation through the lenses of biological evolution. *Journal of The Royal Society Interface*, **12** (2014). doi:10.1098/rsif.2014.1183.

[182] Kettley, S., Kettley, R., and Bates, M. Workshop on Participatory Design and the Humanist Landscape. In *Adjunct Proc. of the 2015 ACM Int. Joint Conf. on Pervasive and Ubiquitous Computing (UBICOMP '15) and of the 2015 ACM Int. Symposium on Wearable Computers (ISWC '15)*, pp. 1093–1094. ACM (2015). ISBN 978-1-4503-3575-1. Available from: http://doi.acm.org/10.1145/2800835.2808080, doi:10.1145/2800835.2808080.

[183] Kim, J. and Jun, H. Vision-based location positioning using augmented reality for indoor navigation. *IEEE Transactions on Consumer Electronics*, **54** (2008), 954. doi:10.1109/TCE.2008.4637573.

[184] Kitchenham, B. Procedures for performing systematic reviews. *Keele, UK, Keele University 33(2004)*, (2004), 1.

[185] Knoester, D. B., Goldsby, H. J., and McKinley, P. K. Genetic variation and the evolution of consensus in digital organisms. *IEEE Transactions on Evolutionary Computation*, **17** (2013), 403. doi:10.1109/TEVC.2012.2201725.

[186] Koay, K. L., Syrdal, D. S., Ashgari-Oskoei, M., Walters, M. L., and Dautenhahn, K. Social roles and baseline proxemic preferences for a domestic service robot. *International Journal of Social Robotics*, **6** (2014), 469. Available from: https://doi.org/10.1007/s12369-014-0232-4, doi:10.1007/s12369-014-0232-4.

[187] Kohlhammer, J., Keim, D., Pohl, M., Santucci, G., and Andrienko, G. Solving problems with visual analytics. In *Procedia Computer Science*, vol. 7, pp. 117–120 (2011). doi:10.1016/j.procs.2011.12.035.

[188] Kruger, A. Innovative retail laboratory: Assistive technologies in retail environments. In *Proceedings of the 2011 Workshop on Context-awareness in Retrieval and Recommendation*, CaRR '11, pp. 1–1. New York, NY, USA (2011). ISBN 978-1-4503-0625-6. Available from: http://doi.acm.org/10.1145/1961634.1961635.

[189] Kulyk, O., Kosara, R., Urquiza, J., and Wassink, I. *Human-Centered Visualization Environments: GI-Dagstuhl Research Seminar, Dagstuhl Castle, Germany, March 5-8, 2006, Revised Lectures*, chap. Human-Centered Aspects, pp. 13–75. Springer Berlin Heidelberg, Berlin, Heidelberg (2007). ISBN 978-3-540-71949-6. Available from: http://dx.doi.org/10.1007/978-3-540-71949-6_2, doi:10.1007/978-3-540-71949-6_2.

[190] Kyng, M. Democracy Beyond Projects: How Users May Achieve Lasting Influence on It Systems. *Interactions*, **23** (2016), 36. Available from: http://doi.acm.org/10.1145/2889276, doi:10.1145/2889276.

[191] Langley, A. Strategies for theorizing from process data. *The Academy of Management Review*, **24** (1999), 691. Available from: http://www.jstor.org/stable/259349.

[192] Laxmisan, A., Hakimzada, F., Sayan, O. R., Green, R. A., Zhang, J., and Patel, V. L. The multitasking clinician: decision-making and cognitive demand during and after team handoffs in emergency care. *International journal of medical informatics*, **76** (2007).

[193] Lee, J., McCullough, J. S., and Town, R. J. The impact of health information technology on hospital productivity. *The RAND Journal of Economics*, **44** (2013), 545.

[194] Leischnig, A., Ivens, B., Wölfl, S., and Hein, D. *Service Digitization – Review of the Literature and Research Agenda*, pp. 43–59. Springer Fachmedien Wiesbaden, Wiesbaden (2017). ISBN 978-3-658-17550-4. Available from: https://doi.org/10.1007/978-3-658-17550-4_2, doi:10.1007/978-3-658-17550-4_2.

[195] Lenz, R. and Reichert, M. It support for healthcare processes ? premises, challenges, perspectives. *Data & Knowledge Engineering*, **61** (2007), 39 . Business Process Management. Available from: http://www.sciencedirect.com/science/article/pii/S0169023X06000784, doi:https://doi.org/10.1016/j.datak.2006.04.007.

[196] Lenz, R. and Reichert, M. IT support for healthcare processes–premises, challenges, perspectives. *Data & Knowledge Engineering*, **61** (2007), 39.

[197] Leonardi, G., Panzarasa, S., Quaglini, S., Stefanelli, M., and van der Aalst, W. M. P. Interacting Agents through a Web-based Health Serviceflow Management System. *Journal of Biomedical Informatics*, **40** (2007), 486.

[198] Leppäkoski, H., Collin, J., and Takala, J. Pedestrian navigation based on inertial sensors, indoor map, and wlan signals. In *2012 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, pp. 1569–1572 (2012). doi:10.1109/ICASSP.2012.6288192.

[199] Levitt, T. The industrialization of service. *Harvard Business Review*, **545** (1976), 63.

[200] Li, L., Zhao, C., Zhao, F., and Shen, J. Travi-navi: Self-deployable indoor navigation system. In *Mobicom'14*. ACM Association for Computing Machinery (2014). Available from: https://www.microsoft.com/en-us/research/publication/travi-navi-self-deployable-indoor-navigation-system/.

[201] Liang, G. and Xu, X. Residential area streetlight intelligent monitoring management system based on zigbee and gprs. *AIP Conference Proceedings 1839, 020213*, (2017). doi:https://doi.org/10.1063/1.4982578.

[202] Lillrank, P. and Liukko, M. Standard, routine and non-routine processes in health care. *International Journal of Health Care Quality Assurance*, **17** (2004), 39.

[203] Lin, C.-H., Shih, H.-Y., and Sher, P. Integrating technology readiness into technology acceptance: The tram model. *Psychology and Marketing*, **24** (2007), 641 . doi:10.1002/mar.20177.

[204] Lindsay, S., Jackson, D., Schofield, G., and Olivier, P. Engaging Older People Using Participatory Design. In *Proc. of the 2012 SIGCHI Conference on Human Factors in Computing Systems (CHI '12)*, pp. 1199–1208. ACM (2012). ISBN 978-1-4503-1015-4. Available from: http://doi.acm.org/10.1145/2207676.2208570, doi:10.1145/2207676.2208570.

[205] Linga, Z. and Anqingb, Z. Design of energy-saving intelligent led illumination system (2008). Available from: http://en.cnki.com.cn/Article_en/CJFDTotal-BDTJ200802011.htm.

[206] Link, J. B., Smith, P., Viol, N., and Wehrle, K. Accurate map-based indoor navigation on the mobile. *J. Locat. Based Serv.*, **7** (2013), 23. Available from: http://dx.doi.org/10.1080/17489725.2012.692620, doi:10.1080/17489725.2012.692620.

[207] Lisetti, C., Nasoz, F., LeRouge, C., Ozyer, O., and Alvarez, K. Developing multimodal intelligent affective interfaces for tele-home health care. *International Journal of Human-Computer Studies*, **59** (2003), 245 . Applications of Affective Computing in Human-Computer Interaction. Available from: http://www.sciencedirect.com/science/article/pii/S107158190300051X, doi:https://doi.org/10.1016/S1071-5819(03)00051-X.

[208] Livnat, A. and Papadimitriou, C. Sex as an algorithm: The theory of evolution under the lens of computation. *Commun. ACM*, **59** (2016), 84. Available from: http://doi.acm.org/10.1145/2934662, doi:10.1145/2934662.

[209] López-Cózar, R. and Callejas, Z. Multimodal dialogue for ambient intelligence and smart environments. In *Handbook of ambient intelligence and smart environments*, pp. 559–579. Springer (2010).

[210] Loreto, V., Servedio, V. D. P., Strogatz, S. H., and Tria, F. *Dynamics on Expanding Spaces: Modeling the Emergence of Novelties*, pp. 59–83. Springer International Publishing, Cham (2016). ISBN 978-3-319-24403-7.

[211] Lv, X. and Chen, Y. A design of autonomous tracing in intelligent vehicle based on infrared photoelectric sensor. In *2009 International Conference on Information Engineering and Computer Science*, pp. 1–4 (2009). doi:10.1109/ICIECS.2009.5365003.

[212] M. Poulymenopoulou et al. Emergency healthcare process automation using workflow technology and web services. *Medical Informatics and the Internet in Medicine*, **28** (2003), 195.

[213] Ma, X., Lu, S., and Yang, K. Service-Oriented Architecture for SPDFLOW: A Healthcare Workflow System for Sterile Processing Departments. In *IEEE Ninth International Conference on Services Computing (SCC)*, pp. 507–514 (2012).

[214] Maggi, F. M., Corapi, D., Russo, A., Lupu, E., and Visaggio, G. Revising process models through inductive learning. In *Business Process Management Workshops* (edited by M. zur Muehlen and J. Su), pp. 182–193. Springer Berlin Heidelberg, Berlin, Heidelberg (2011). ISBN 978-3-642-20511-8.

[215] Maggi, F. M., Marrella, A., Capezzuto, G., and Cervantes, A. A. Explaining non-compliance of business process models through automated planning. In *Service-Oriented Computing* (edited by C. Pahl, M. Vukovic, J. Yin, and Q. Yu), pp. 181–197. Springer International Publishing, Cham (2018).

[216] Makhlouf, A., Nedjai, I., Saadia, N., and Ramdane-Cherif, A. Multimodal system for fall detection and location of person in an intelligent habitat. *Procedia Computer Science*, **109** (2017), 969 . 8th International Conference on Ambient Systems, Networks and Technologies, ANT-2017 and the 7th International Conference on Sustainable Energy Information Technology, SEIT 2017, 16-19 May 2017, Madeira, Portugal. Available from: http://www.sciencedirect.com/science/article/pii/S1877050917311389, doi:https://doi.org/10.1016/j.procs.2017.05.455.

[217] Mans, R. S., van der Aalst, W. M., and Vanwersch, R. J. *Process mining in healthcare: evaluating and exploiting operational healthcare processes*. Springer (2015).

[218] Mans, R. S., van der Aalst, W. M. P., Russell, N. C., and Bakker, P. J. M. Flexibility Schemes for Workflow Management Systems. In *2nd International Workshop on Process-Oriented Information Systems in Healthcare*, pp. 361–372 (2009).

[219] Mans, R. S., van der Aalst, W. M. P., Russell, N. C., Bakker, P. J. M., and Moleman, A. J. *Process-Aware Information System Development for the Healthcare Domain - Consistency, Reliability, and Effectiveness*, pp. 635–646. Springer Berlin Heidelberg, Berlin, Heidelberg (2010).

[220] Manzini, E. and Coad, R. *Design, when everybody designs: An introduction to design for social innovation*. MIT Press (2015).

[221] Margalit, R. S., Roter, D., Dunevant, M. A., Larson, S., and Reis, S. Electronic medical record use and physician–patient communication: an observational study of israeli primary care encounters. *Patient education and counseling*, **61** (2006), 134.

[222] Marrella, A., Mecella, M., and Russo, A. Collaboration on-the-field: suggestions and beyond. In *8th International Conference on Information Systems for Crisis Response and Management (ISCRAM)* (2011).

[223] Marrella, A., Mecella, M., and Sardina, S. Intelligent Process Adaptation in the SmartPM System. *ACM Trans. Intell. Syst. Technol.*, **8** (2016), 25:1. Available from: http://doi.acm.org/10.1145/2948071, doi:10.1145/2948071.

[224] Marrella, A., Mecella, M., and Sardiña, S. Supporting adaptiveness of cyber-physical processes through action-based formalisms. *AI Communications*, **31** (2018), 47. doi:10.3233/AIC-170748.

[225] Marrella, A., Mecella, M., Sharf, M., and Catarci, T. The TESTMED project experience. process-aware enactment of clinical guidelines through multimodal interfaces. *CoRR*, **abs/1807.02022** (2018). Available from: http://arxiv.org/abs/1807.02022, arXiv:1807.02022.

[226] Martirano, L. Lighting systems to save energy in educational classrooms. In *2011 10th International Conference on Environment and Electrical Engineering*, pp. 1–5 (2011). doi:10.1109/EEEIC.2011.5874691.

[227] Martirano, L. A smart lighting control to save energy. In *Proceedings of the 6th IEEE International Conference on Intelligent Data Acquisition and Advanced Computing Systems*, vol. 1, pp. 132–138 (2011). doi:10.1109/IDAACS.2011.6072726.

[228] Marx, M., Carter, J., Phillips, M., Holthouse, M., Seabury, S., Elizondo-Cecenas, J., and Phaneuf, B. System and method for developing interactive speech applications (2001). US Patent 6,173,266. Available from: https://www.google.com/patents/US6173266.

[229] Masin, M., Limonad, L., Sela, A., Boaz, D., Greenberg, L., Mashkif, N., and Rinat, R. Pluggable analysis viewpoints for design space exploration. *Procedia Computer Science*, **16** (2013), 226.

[230] Matta, S. and Mahmud, S. M. An intelligent light control system for power saving. In *IECON 2010 - 36th Annual Conference on IEEE Industrial Electronics Society*, pp. 3316–3321 (2010). doi:10.1109/IECON.2010.5675331.

[231] Mayer, J. M. and Zach, J. Lessons Learned from Participatory Design with and for People with Dementia. In *Proc. of the 15th Int. Conf. on Human-computer Interaction with Mobile Devices and Services*, MobileHCI '13, pp. 540–545. ACM (2013). ISBN 978-1-4503-2273-7. Available from: http://doi.acm.org/10.1145/2493190.2494436, doi:10.1145/2493190.2494436.

[232] McGee-Lennon, M. R., Carberry, M., and Gray, P. D. HECTOR: A PDA Based Clinical Handover System. Tech. rep., DCS Technical Report Series. Glasgow, UK: Department of Computing Science, University of Glasgow, UK, 2007: 1–14 (2007).

[233] Minker, J. *Logic-based artificial intelligence*, vol. 597. Springer Science & Business Media (2012).

[234] Mitchell, M. *An Introduction to Genetic Algorithms*. MIT Press, Cambridge, MA, USA (1998). ISBN 0262631857.

[235] Mitsunaga, N., Smith, C., Kanda, T., Ishiguro, H., and Hagita, N. Adapting robot behavior for human–robot interaction. *IEEE Transactions on Robotics*, **24** (2008), 911. doi:10.1109/TRO.2008.926867.

[236] Mori, K. *Concept-Oriented Research and Development in Information Technology*. Wiley Publishing, 1st edn. (2014). ISBN 1118478916, 9781118478912.

[237] Mulloni, A., Seichter, H., and Schmalstieg, D. Handheld augmented reality indoor navigation with activity-based instructions. In *Proceedings of the 13th International Conference on Human Computer Interaction with Mobile Devices and Services*, MobileHCI '11, pp. 211–220. ACM, New York, NY, USA (2011). ISBN 978-1-4503-0541-9. Available from: http://doi.acm.org/10.1145/2037373.2037406, doi:10.1145/2037373.2037406.

[238] Mulloni, A., Wagner, D., Barakonyi, I., and Schmalstieg, D. Indoor positioning and navigation with camera phones. *IEEE Pervasive Computing*, **8** (2009), 22. doi:10.1109/MPRV.2009.30.

[239] Mumm, J. and Mutlu, B. Human-robot proxemics: Physical and psychological distancing in human-robot interaction. In *2011 6th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*, pp. 331–338 (2011). doi:10.1145/1957656.1957786.

[240] Mumolo, E., Nolich, M., and Vercelli, G. Pro-active service robots in a health care framework: vocal interaction using natural language and prosody. In *Proceedings 10th IEEE International Workshop on Robot and Human Interactive Communication. ROMAN 2001 (Cat. No.01TH8591)*, pp. 606–611 (2001). doi:10.1109/ROMAN.2001.981971.

[241] Münster, M. and Meiren, T. *Internet-basierte Services im Maschinen- und Anlagenbau: Ergebnisse einer empirischen Untersuchung*. Fraunhofer Verlag (2011). ISBN 9783839602447. Available from: https://books.google.de/books?id=ZXSypwAACAAJ.

[242] Murray, R., Caulier-Grice, J., and Mulgan, G. *The open book of social innovation*. National endowment for science, technology and the art London (2010).

[243] Nikolaidis, S., Ramakrishnan, R., Gu, K., and Shah, J. Efficient model learning from joint-action demonstrations for human-robot collaborative tasks. In *Proceedings of the Tenth Annual ACM/IEEE International Conference on Human-Robot Interaction*, HRI '15, pp. 189–196. ACM, New York, NY, USA (2015). ISBN 978-1-4503-2883-8. Available from: http://doi.acm.org/10.1145/2696454.2696455, doi:10.1145/2696454.2696455.

[244] Nilsson, T. Smart spaces: Challenges and opportunities of ble-centered mobile systems for public environments. *CoRR*, **abs/1703.08717** (2017). Available from: http://arxiv.org/abs/1703.08717.

[245] Norman, D. A. and Draper, S. W. User Centered System Design. *New Perspectives on Human-Computer Interaction, L. Erlbaum Associates Inc., Hillsdale, NJ*, (1986).

[246] Olsson, T. *User Expectations and Experiences of Mobile Augmented Reality Services*. Tampere University of Technology. Publication. Tampere University of Technology (2012). ISBN 978-952-15-2931-3.

[247] Ottani, F., et al. Percorso di valutazione del dolore toracico - Valutazione dei requisiti di base per l'implementazione negli ospedali italiani. *Giornale Italiano di Cardiologia*, **10** (2009), 46.

[248] Oviatt, S. and Cohen, P. R. The paradigm shift to multimodality in contemporary computer interfaces. *Synthesis Lectures On Human-Centered Informatics*, **8** (2015), 1.

[249] Oviatt, S., Coulston, R., and Lunsford, R. When do we interact multimodally?: cognitive load and multimodal communication patterns. In *Proceedings of the 6th international conference on Multimodal interfaces*, pp. 129–136. ACM (2004).

[250] Ozdenizci, B., Ok, K., Coskun, V., and Aydin, M. N. Development of an indoor navigation system using nfc technology. In *2011 Fourth International Conference on Information and Computing*, pp. 11–14 (2011). doi:10.1109/ICIC.2011.53.

[251] Papagelis, M., Murdock, V., and van Zwol, R. Individual behavior and social influence in online social systems. In *Proc. of the 22Nd ACM Conference on Hypertext and Hypermedia*, HT '11, pp. 241–250. ACM, New York, NY, USA (2011). ISBN 978-1-4503-0256-2.

[252] Parasuraman, A. P., Zeithaml, V., and Malhotra, A. E-s-qual: A multiple-item scale for assessing electronic service quality. *Journal of Service Research*, **7** (2005), 213. doi:10.1177/1094670504271156.

[253] Peleg, M. and Tu, S. W. Design patterns for clinical guidelines. *Artificial Intelligence in Medicine*, **47** (2009), 1.

[254] Peleg, M., et al. Comparing Computer-Interpretable Guideline Models: A Case-Study Approach. *Journal of the AMIA*, **10** (2003), 52.

[255] Peng, L., Di, S., and Dou, N. Zigbee wireless energy-saving lamps control system based on cc2480 (2009). Available from: http://en.cnki.com.cn/Article_en/CJFDTotal-TXJS200901127.htm.

[256] Pfeffer, J. *Administrative Science Quarterly*, **28** (1983), 321. Available from: http://www.jstor.org/stable/2392635.

[257] Pieh, C., Neumeier, S., Loew, T., Altmeppen, J., Angerer, M., Busch, V., and Lahmann, C. Effectiveness of a multimodal treatment program for somatoform pain disorder. *Pain Practice*, **14** (2014).

[258] Pilemalm, S. Participatory design in emerging civic engagement initiatives in the new public sector: Applying PD concepts in resource-scarce organizations. *ACM Transactions on Computer-Human Interaction (TOCHI)*, **25** (2018), 5.

[259] Piller, F. T. and Tseng, M. M. *Handbook of research in mass customization and personalization*, vol. 1. World Scientific Publishing Co. Pte. Ltd. (2010).

[260] Pinheiro, F., Santos, M., Santos, F., and Pacheco, J. Origin of peer influence in social networks. *Physical Review Letters*, **112** (2014). doi:10.1103/PhysRevLett.112.098702.

[261] Plattner, H., Meinel, C., and Leifer, L. *Design Thinking: Understand - Improve - Apply*. Springer Publishing Company, Incorporated, 1st edn. (2010). ISBN 9783642137563.

[262] Potamianos, G. Audio-visual automatic speech recognition and related bimodal speech technologies: A review of the state-of-the-art and open problems. In *2009 IEEE Workshop on Automatic Speech Recognition Understanding*, pp. 22–22 (2009). doi:10.1109/ASRU.2009.5373530.

[263] Poulymenopoulou, M., Malamateniou, F., and Vassilacopoulos, G. Emergency healthcare process automation using mobile computing and cloud services. *Journal of Medical Systems*, **36** (2012).

[264] Preece, J., Rogers, Y., and Sharp, H. *Beyond Interaction Design: Beyond Human-Computer Interaction*. John Wiley & Sons, Inc., New York, NY, USA (2001). ISBN 0471402494.

[265] Prins, R. and Verhoef, P. Marketing communication drivers of adoption timing of a new e-service among existing customers. *Erasmus Research Institute of Management (ERIM), ERIM is the joint research institute of the Rotterdam School of Management, Erasmus University and the Erasmus School of Economics (ESE) at Erasmus Uni, Research Paper*, **71** (2007). doi:10.1509/jmkg.71.2.169.

[266] Puikkonen, A., Sarjanoja, A.-H., Haveri, M., Huhtala, J., and Häkkilä, J. Towards designing better maps for indoor navigation: Experiences from a case study. In *Proceedings of the 8th International Conference on Mobile and Ubiquitous Multimedia*, MUM '09, pp. 16:1–16:4. ACM, New York, NY, USA (2009). ISBN 978-1-60558-846-9. Available from: http://doi.acm.org/10.1145/1658550.1658566, doi:10.1145/1658550.1658566.

[267] Purohit, A., Sun, Z., Pan, S., and Zhang, P. Sugartrail: Indoor navigation in retail environments without surveys and maps. In *2013 IEEE International Conference on Sensing, Communications and Networking (SECON)*, pp. 300–308 (2013). doi:10.1109/SAHCN.2013.6644999.

[268] Qaurooni, D., Ghazinejad, A., Kouper, I., and Ekbia, H. Citizens for Science and Science for Citizens: The View from Participatory Design. In *Proc. of the 2016 SIGCHI Conference on Human Factors in Computing Systems (CHI '16)*, pp. 1822–1826. ACM (2016).

[269] Qin, L., Dong, L., Xu, W., Zhang, L., Yan, Q., and Chen, X. A ?vehicle in, light brightens; vehicle out, light darkens? energy-saving control system of highway tunnel lighting. *Tunnelling and Underground Space Technology*, **66** (2017), 147 . Available from: http://www.sciencedirect.com/science/article/pii/S0886779816302802, doi:https://doi.org/10.1016/j.tust.2017.04.014.

[270] Rakubutu, T., Gelderblom, H., and Cohen, J. Participatory Design of Touch Gestures for Informational Search on a Tablet Device. In *Proc. of the Southern African Institute for Computer Scientist and Information Technologists (SAICSIT 2014)*, pp. 276:276–276:285. ACM (2014). ISBN 978-1-4503-3246-0. Available from: http://doi.acm.org/10.1145/2664591.2664594, doi:10.1145/2664591.2664594.

[271] RAN, L. Drishti : an integrated indoor/outdoor blind navigation system and service. *Second IEEE International Conference on Pervasive Comput. Commun., 2004*, (2004), 23. Available from: http://ci.nii.ac.jp/naid/10029237722/en/.

[272] Read, J. C., Horton, M., Sim, G., Gregory, P., Fitton, D., and Cassidy, B. CHECk: A Tool to Inform and Encourage Ethical Practice in Participatory Design with Children. In *Proc. of the 2013 SIGCHI Conference on Human Factors in Computing Systems (CHI '13) - Extended Abstracts*, pp. 187–192. ACM (2013). ISBN 978-1-4503-1952-2. Available from: http://doi.acm.org/10.1145/2468356.2468391, doi:10.1145/2468356.2468391.

[273] Reichert, M. What BPM Technology Can Do for Healthcare Process Support. In *Artificial Intelligence in Medicine* (edited by M. Peleg, N. Lavrač, and C. Combi), pp. 2–13. Springer Berlin Heidelberg, Berlin, Heidelberg (2011). ISBN 978-3-642-22218-4.

[274] Remy, S. L. and Blake, M. B. Distributed service-oriented robotics. *IEEE Internet Computing*, **15** (2011), 70. doi:10.1109/MIC.2011.38.

[275] Renaudin, V., Yalak, O., TomÃ©, P., and Merminod, B. Inertial and rfid sensors for indoor navigation in case of emergency intervention. *European Journal of Navigation*, (2017).

[276] Riccio, F., Vanzo, A., Mirabella, V., Catarci, T., and Nardi, D. Enabling symbiotic autonomy in short-term interactions: A user study. vol. 9979, pp. 796–807 (2016). ISBN 978-3-319-47436-6. doi:10.1007/978-3-319-47437-3_78.

[277] Richtel, M. As doctors use more devices, potential for distraction grows. *The New York Times*, **14** (2011).

[278] Riek, L. D. Wizard of oz studies in hri: A systematic review and new reporting guidelines. *J. Hum.-Robot Interact.*, **1** (2012), 119. Available from: https://doi.org/10.5898/JHRI.1.1.Riek, doi:10.5898/JHRI.1.1.Riek.

[279] Rifkin, J. The age of access: The new culture of hypercapitalism. *Where All of Life is a Paid-For Experience, Tarcher, New York*, **33** (2000), 40.

[280] Rifkin, J. *The third industrial revolution: how lateral power is transforming energy, the economy, and the world*. Macmillan (2011).

[281] Rifkin, J. *The zero marginal cost society: The internet of things, the collaborative commons, and the eclipse of capitalism*. Macmillan (2014).

[282] Rojchaya, S. and Konghirun, M. Development of energy management and warning system for resident: An energy saving solution. In *2009 6th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology*, vol. 01, pp. 426–429 (2009). doi:10.1109/ECTICON.2009.5137040.

[283] Rojo, M. G., et al. Implementation of the Business Process Modelling Notation (BPMN) in the modelling of anatomic pathology processes. *Diagnostic Pathology*, **3 Suppl 1** (2008).

[284] Rosenthal, S., Biswas, J., and Veloso, M. An effective personal mobile robot agent through symbiotic human-robot interaction. In *Proceedings of the 9th International Conference on Autonomous Agents and Multiagent Systems: Volume 1 - Volume 1*, AAMAS '10, pp. 915–922. International Foundation for Autonomous Agents and Multiagent Systems, Richland, SC (2010). ISBN 978-0-9826571-1-9. Available from: http://dl.acm.org/citation.cfm?id=1838206.1838329.

[285] Rosenthal, S. and Veloso, M. Mobile robot planning to seek help with spatially-situated tasks. In *Proceedings of the Twenty-Sixth AAAI Conference on Artificial Intelligence*, AAAI'12, pp. 2067–2073. AAAI Press (2012). Available from: http://dl.acm.org/citation.cfm?id=2900929.2901020.

[286] Roto, V., Väätäjä, H., Law, E., and Powers, R. Experience design for multiple customer touchpoints. In *Proceedings of the 9th Nordic Conference on Human-Computer Interaction*, NordiCHI '16, pp. 146:1–146:3. ACM, New York, NY, USA (2016). ISBN 978-1-4503-4763-1. Available from: http://doi.acm.org/10.1145/2971485.2987685, doi:10.1145/2971485.2987685.

[287] Ruiz, A. R. J., Granja, F. S., Honorato, J. C. P., and Rosas, J. I. G. Accurate pedestrian indoor navigation by tightly coupling foot-mounted imu and rfid measurements. *IEEE Transactions on Instrumentation and Measurement*, **61** (2012), 178. doi:10.1109/TIM.2011.2159317.

[288] Ruiz, F., Garcia, F., Calahorra, L., Llorente, C., Goncalves, L., Daniel, C., and Blobel, B. Business process modeling in healthcare. *Studies in Health Technology and Informatics*, **179** (2012), 75.

[289] Rushkoff, D. Renaissance Now! Media Ecology and the New Global Narrative. *Explorations in Media Ecology*, **1** (2002), 41.

[290] Russo, A. and Mecella, M. On the evolution of process-oriented approaches ï¿Œfo rhealthcare workflows. *Int. J. Business Process Integration and Management*, **3** (2013).

[291] Rust, R. T. and Lemon, K. N. E-service and the consumer. *Int. J. Electron. Commerce*, **5** (2001), 85. Available from: https://doi.org/10.1080/10864415.2001.11044216, doi:10.1080/10864415.2001.11044216.

[292] Saad-Sulonen, J., Halskov, K., Huybrechts, L., Vines, J., Eriksson, E., and Karasti, H. Unfolding Participation. What do we mean by participation ? conceptually and in practice. *Aarhus Series on Human Centered Computing*, **1** (2015), 4. Available from: http://ojs.statsbiblioteket.dk/index.php/ashcc/article/view/21324, doi:10.7146/aahcc.v1i1.21324.

[293] Salomann, H., M. Kolbe, L., and Brenner, W. Self-services in customer relationships: Balancing high-tech and high-touch today and tomorrow. *University of St.Gallen*, **4** (2006). doi:10.2979/ESJ.2006.4.2.65.

[294] Salvador, F., De Holan, P. M., and Piller, F. T. Cracking the code of mass customization. *MIT Sloan Management Review*, **50** (2009), 71.

[295] Sauro, J. and Lewis, J. R. *Quantifying the user experience: Practical statistics for user research*. Morgan Kaufmann (2016).

[296] Sawy, O., Malhotra, A., Park, Y., and Pavlou, P. Seeking the configurations of digital ecodynamics: It takes three to tango. *Information Systems Research*, **21** (2010), 835. doi:10.1287/isre.1100.0326.

[297] Serra, A., Carboni, D., and Marotto, V. Indoor pedestrian navigation system using a modern smartphone. In *Proceedings of the 12th International Conference on Human Computer Interaction with Mobile Devices and Services*, MobileHCI '10, pp. 397–398. ACM, New York, NY, USA (2010). ISBN 978-1-60558-835-3. Available from: http://doi.acm.org/10.1145/1851600.1851683, doi:10.1145/1851600.1851683.

[298] Setia, P., Venkatesh, V., and Joglekar, S. Leveraging digital technologies: How information quality leads to localized capabilities and customer service performance. *MIS Quarterly*, **37** (2013), 565. doi:10.25300/MISQ/2013/37.2.11.

[299] Shachak, A., Hadas-Dayagi, M., Ziv, A., and Reis, S. Primary care physicians use of an eletronic medical recors system: a cognitive task analysis. *Journal of general internal medicine*, **24** (2009).

[300] Sharma, R., Yeasin, M., Krahnstoever, N., Rauschert, I., Cai, G., Brewer, I., MacEachren, A. M., and Sengupta, K. Speech-gesture driven multimodal interfaces for crisis management. *Proceedings of the IEEE*, **91** (2003), 1327. doi:10.1109/JPROC.2003.817145.

[301] Shen, S., Michael, N., and Kumar, V. Autonomous multi-floor indoor navigation with a computationally constrained mav. In *2011 IEEE International Conference on Robotics and Automation*, pp. 20–25 (2011). doi:10.1109/ICRA.2011.5980357.

[302] Simoens, P., Dragone, M., and Saffiotti, A. The internet of robotic things: A review of concept, added value and applications. *International Journal of Advanced Robotic Systems*, **15** (2018), 1729881418759424. Available from: https://doi.org/10.1177/1729881418759424, arXiv:https://doi.org/10.1177/1729881418759424, doi:10.1177/1729881418759424.

[303] Singh, P. J. and Gurumurthy, A. *Establishing Public-ness in the Network: New Moorings for Development?A Critique of the Concepts of Openness and Open Development*, vol. 7. Open Development: Networked Innovations in International Development (2013).

[304] Slavich, G. and Buonocore., G. Iforensic medicine aspects in patients with chest pain in the emergency room. *Italian Heart J. Suppl.*, **2** (2001), 381.

[305] Soh, C. and Markus, M. L. How it creates business value: a process theory synthesis. In *Proceedings of the sixteenth International Conference on Information Systems*, pp. 29–41 (1995).

[306] Sohn, C. and K. Tadisina, S. Development of e-service quality measure for internet-based financial institutions. *Total Quality Management*, **19** (2008), 903. doi:10.1080/14783360802224412.

[307] Song, H.-g., Restivo, M., Rijt, A., Scarlatos, L., Tonjes, D., and Orlov, A. The hidden gender effect in online collaboration: An experimental study of team performance under anonymity. *Computers in Human Behavior*, **50** (2015). doi:10.1016/j.chb.2015.04.013.

[308] Sonnenberg, F. A. and Hagerty, C. G. Computer-Interpretable Clinical Practice Guidelines. Where are we and where are we going? *Yearbook of Medical Informatics*, **45** (2006), 145.

[309] STANGE, E. Influencing factors on user acceptance of location-based advertising outside and inside retail stores. *Lisboa: ISCTE-IUL*, (2015). Available from: http://hdl.handle.net/10071/11475.

[310] Stoffel, E.-P., Lorenz, B., and Ohlbach, H. J. *Towards a Semantic Spatial Model for Pedestrian Indoor Navigation*, pp. 328–337. Springer Berlin Heidelberg, Berlin, Heidelberg (2007). ISBN 978-3-540-76292-8. Available from: https://doi.org/10.1007/978-3-540-76292-8_39, doi:10.1007/978-3-540-76292-8_39.

[311] Storms, W., Shockley, J., and Raquet, J. Magnetic field navigation in an indoor environment. In *2010 Ubiquitous Positioning Indoor Navigation and Location Based Service*, pp. 1–10 (2010). doi:10.1109/UPINLBS.2010.5653681.

[312] Strasser, M., Pfeifer, F., Helm, E., Schuler, A., and Altmann, J. Defining and reconstructing clinical processes based on IHE and BPMN 2.0. *Studies in Health Technology and Informatics*, **169** (2011).

[313] Sturm, A. and Shehory, O. Agent-oriented software engineering: revisiting the state of the art. In *Agent-Oriented Software Engineering*, pp. 13–26. Springer (2014).

[314] Sun, J., Su, J., Zhang, G., Li, Y., and Zhao, C. An energy-saving control method based on multi-sensor system for solar street lamp. In *2010 International Conference on Digital Manufacturing Automation*, vol. 1, pp. 192–194 (2010). doi:10.1109/ICDMA.2010.210.

[315] Sutton, D. R. and Fox, J. The syntax and semantics of the proforma guideline modeling language. *Journal of the American Medical Informatics Association*, **10** (2003), 433.

[316] Swenson, K. D. (ed.). *Mastering the Unpredictable: How Adaptive Case Management Will Revolutionize the Way That Knowledge Workers Get Things Done*, chap. 8: Healthcare. Meghan-Kiffer Press (2010).

[317] Syrdal, D. S., Lee Koay, K., Walters, M. L., and Dautenhahn, K. A personalized robot companion? - the role of individual differences on spatial preferences in hri scenarios. In *RO-MAN 2007 - The 16th IEEE International Symposium on Robot and Human Interactive Communication*, pp. 1143–1148 (2007). doi:10.1109/ROMAN.2007.4415252.

[318] Takayama, L. and Pantofaru, C. Influences on proxemic behaviors in human-robot interaction. In *2009 IEEE/RSJ International Conference on Intelligent Robots and Systems*, pp. 5495–5502 (2009). doi:10.1109/IROS.2009.5354145.

[319] Tan, Y. K., Huynh, T. P., and Wang, Z. Smart personal sensor network control for energy saving in dc grid powered led lighting system. *IEEE Transactions on Smart Grid*, **4** (2013), 669. doi:10.1109/TSG.2012.2219887.

[320] Toffler, A. and Alvin, T. *The third wave*. Bantam Books (1981).

[321] Torta, E., Cuijpers, R. H., and Juola, J. F. A model of the user's proximity for bayesian inference. In *Proceedings of the 6th International Conference on Human-robot Interaction*, HRI '11, pp. 273–274. ACM, New York, NY, USA (2011). ISBN 978-1-4503-0561-7. Available from: http://doi.acm.org/10.1145/1957656.1957767, doi:10.1145/1957656.1957767.

[322] Toyama, K. *Geek Heresy: Rescuing Social Change from the Cult of Technology*. Public Affairs (2015). ISBN 978-1610395281.

[323] Tsang, K., Lee, W., Lam, K., Tung, H., and Kai Xuan. An integrated zigbee automation system: An energy saving solution. In *2007 14th International Conference on Mechatronics and Machine Vision in Practice*, pp. 252–258 (2007). doi:10.1109/MMVIP.2007.4430752.

[324] Tsetsos, V., Anagnostopoulos, C., Kikiras, P., and Hadjiefthymiades, S. Semantically enriched navigation for indoor environments. *Int. J. Web Grid Serv.*, **2** (2006), 453. Available from: http://dx.doi.org/10.1504/IJWGS.2006.011714, doi:10.1504/IJWGS.2006.011714.

[325] Twumasi, C., Dotche, K. A., Banuenumah, W., and Sekyere, F. Energy saving system using a pir sensor for classroom monitoring. In *2017 IEEE PES PowerAfrica*, pp. 347–351 (2017). doi:10.1109/PowerAfrica.2017.7991249.

[326] Vainio-Mattila, K., Olsson, T., and Jonna. *Towards Deeper Understanding of User Experience with Ubiquitous Computing Systems: Systematic Literature Review and Design Framework*, pp. 384–401. Lecture Notes in Computer Science. Springer Verlag, Germany (2015). ISBN 978-3-319-22697-2. doi:10.1007/978-3-319-22698-9_26.

[327] Van De Belt, T. H., Engelen, L. J., Berben, S. A., and Schoonhoven, L. Definition of Health 2.0 and Medicine 2.0: a systematic review. *Journal of medical Internet research*, **12** (2010).

[328] van der Aalst, W., et al. Process mining manifesto. In *International Conference on Business Process Management*, pp. 169–194. Springer (2011).

[329] van der Aalst, W. M. *Process mining: data science in action*. Springer (2016).

[330] van der Aalst, W. M. P., Adriansyah, A., and van Dongen, B. F. Replaying history on process models for conformance checking and performance analysis. *Wiley Interdisc. Rew.: Data Mining and Knowledge Discovery*, **2** (2012), 182. doi:10.1002/widm.1045.

[331] van der Aalst, W. M. P., Weijters, T., and Maruster, L. Workflow mining: Discovering process models from event logs. *IEEE Trans. Knowl. Data Eng.*, **16** (2004).

[332] Van Dijk, J., Hendriks, N., Christopher, F., Verhoeven, F., Slegers, K., Brandt, E., and Maldonado Branco, R. Empowering people with impairments: How participatory methods can inform the design of empowering artifacts. In *Proc. of the 14th Participatory Design Conference: Short Papers, Interactive Exhibitions, Workshops*, vol. 2. ACM (2016).

[333] Vanzo, A., Riccio, F., Sharf, M., Mirabella, V., Catarci, T., and Nardi, D. Who is willing to help robots? a user study on collaboration attitude. *International Journal of Social Robotics*, (2019). Available from: https://doi.org/10.1007/s12369-019-00571-6, doi:10.1007/s12369-019-00571-6.

[334] Vardi, M. Y. Technology for the Most Effective Use of Mankind. *Commun. ACM*, **60** (2016), 5. Available from: http://doi.acm.org/10.1145/3020075, doi:10.1145/3020075.

[335] Vines, J., Clarke, R., Wright, P., McCarthy, J., and Olivier, P. Configuring Participation: On How We Involve People in Design. In *Proc. of the 2013 SIGCHI Conference on Human Factors in Computing Systems (CHI '13)*, pp. 429–438. ACM (2013). ISBN 978-1-4503-1899-0. Available from: http://doi.acm.org/10.1145/2470654.2470716, doi:10.1145/2470654.2470716.

[336] Viraktamath, S. V. and Attimarad, G. V. Power saving mechanism for street lights using wireless communication. In *2011 International Conference on Signal Processing, Communication, Computing and Networking Technologies*, pp. 282–285 (2011). doi:10.1109/ICSCCN.2011.6024560.

[337] Vissers, J. and Beech, R. *Health operations management: patient flow logistics in health care*. Psychology Press (2005).

[338] Vitaletti, A. Gende: Genetic design: Best products evolve according to users feedback. *Lecture Notes in Electrical Engineering*, **413** (2017), 101. doi:10.1007/978-3-319-48511-9_9.

[339] Walters, M., Dautenhahn, K., Te Boekhorst, R., Koay, K., Syrdal, D., and Nehaniv, C. An empirical framework for human-robot proxemics. In *Procs of New Frontiers in Human-Robot Interaction*, pp. 144–149 (2009).

[340] Wang, D., Peleg, M., Tu, S., Boxwala, A., Greenes, R., Patel, V., and Shortliffe, E. Representation Primitives, Process Models and Patient Data in Computer-Interpretable Clinical Practice Guidelines: A Literature Review of Guideline Representation Models. *International Journal of Medical Informatics*, **68** (2002), 59.

[341] Wilkinson, C. R. and Angeli, A. D. Applying user centred and participatory design approaches to commercial product development. *Design Studies*, **35** (2014), 614 . Available from: http://www.sciencedirect.com/science/article/pii/S0142694X14000507, doi:http://dx.doi.org/10.1016/j.destud.2014.06.001.

[342] Williams, K., Chatterjee, S., and Rossi, M. Design of emerging digital services: A taxonomy. *European Journal of Information Systems*, **17** (2008). doi:10.1057/ejis.2008.38.

[343] Wright, P. and Blythe, M. User experience research as an inter-discipline: Towards a ux manifesto. In *E. Law, A. Vermeeren, M. Hassenzahl, & M. Blythe (Eds.), Proceedings of the Workshop on Towards a UX Manifesto*, pp. 65–70 (2007).

[344] Wright, P. and McCarthy, J. The politics and aesthetics of participatory HCI. *Interactions*, **22** (2015), 26.

[345] Xu, Q., Zheng, R., and Hranilovic, S. Idyll: Indoor localization using inertial and light sensors on smartphones. In *Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing*, UbiComp '15, pp. 307–318. ACM, New York, NY, USA (2015). ISBN 978-1-4503-3574-4. Available from: http://doi.acm.org/10.1145/2750858.2807540, doi:10.1145/2750858.2807540.

[346] Yang, J., Yang, W., Denecke, M., and Waibel, A. Smart sight: a tourist assistant system. In *iswc*, p. 73. IEEE (1999).

[347] Yao, G. Y. and Song, L. Design of library lighting energy saving system based on internet of things. In *Frontiers of Manufacturing and Design Science IV*, vol. 496 of *Applied Mechanics and Materials*, pp. 1690–1693. Trans Tech Publications Ltd (2014). doi:10.4028/www.scientific.net/AMM.496-500.1690.

[348] Yenicioglu, B. and Suerdem, A. Participatory new product development–a framework for deliberately collaborative and continuous innovation design. *Procedia-Social and Behavioral Sciences*, **195** (2015), 1443.

[349] Zanchettin, A. M., Casalino, A., Piroddi, L., and Rocco, P. Prediction of human activity patterns for human?robot collaborative assembly tasks. *IEEE Transactions on Industrial Informatics*, **15** (2019), 3934. doi:10.1109/TII.2018.2882741.

[350] Zhang, X. and Dai, Y. The intelligent control system of solar lamps based on zigbee wireless network. In *Proceedings of the 2012 International Conference on Electronics, Communications and Control*, ICECC '12, pp. 1722–1725. IEEE Computer Society, Washington, DC, USA (2012). ISBN 978-0-7695-4806-7. Available from: http://dl.acm.org/citation.cfm?id=2417502.2418632.

[351] Zhenhui, T. and Zhengming, Z. Zigbee wireless energy-saving and smart street lights monitoring system based on cc2530 (2011). Available from: http://en.cnki.com.cn/Article_en/CJFDTotal-WXJY201119030.htm.

[352] Zhongfang, Z., Aiping, S., and Tao, L. Single lamp energy conservation control system based on zigbee technology (2008). Available from: http://en.cnki.com.cn/Article_en/CJFDTOTAL-XDDJ200821043.htm.

[353] Zollman, K. Social network structure and the achievement of consensus. *Politics, Philosophy and Economics*, **11** (2012). doi:10.1177/1470594X11416766.

Appendix A

In this part, we provide more details and technical charts about the design and implementation of the first case study regarding the localization-as-a-service chapter.

1 Figures

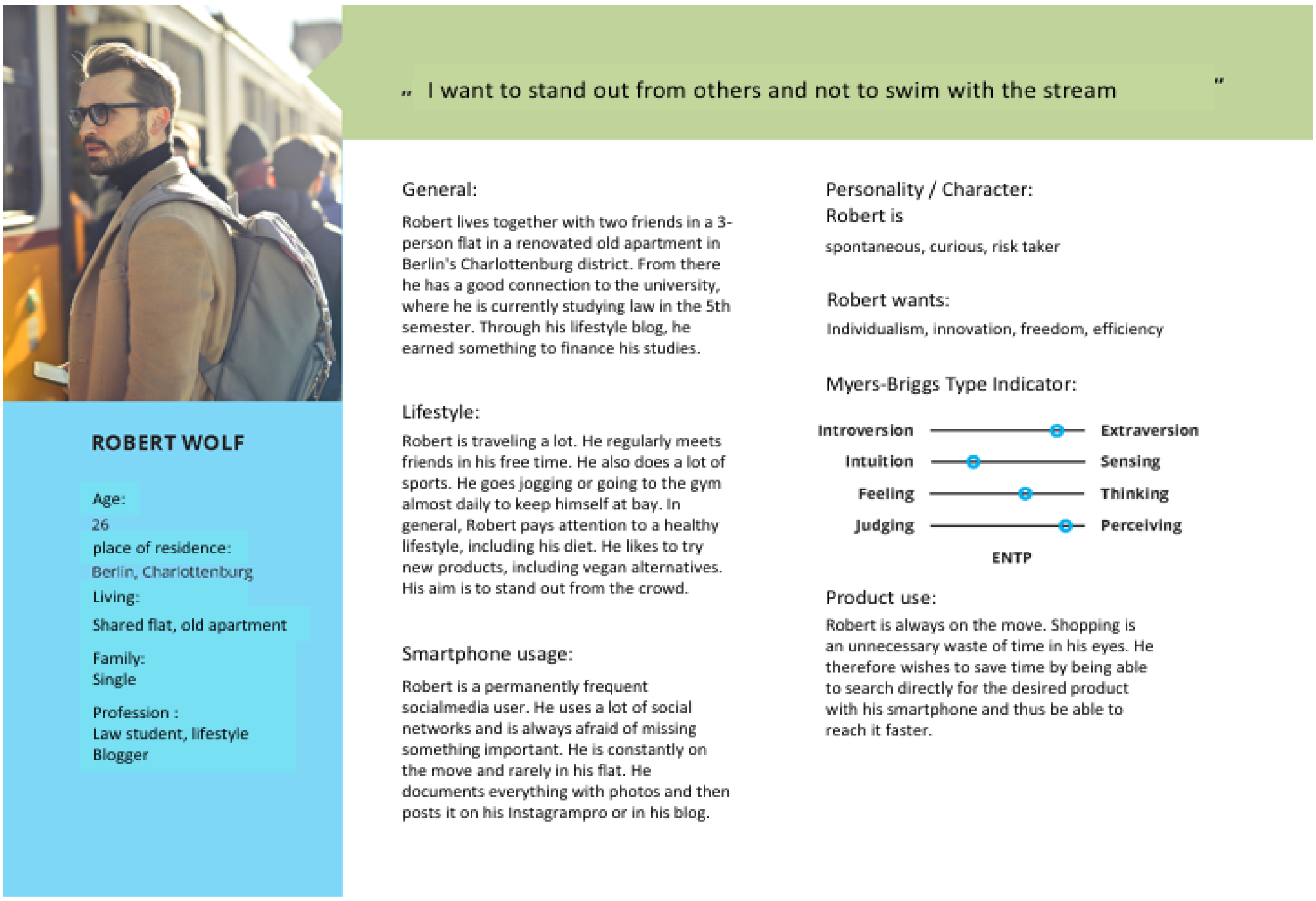


Figure 65. Persona of the actual system user - a retail employee use case.

Figure 66. Second set of the wireframes views for the system's front-end mobile application.

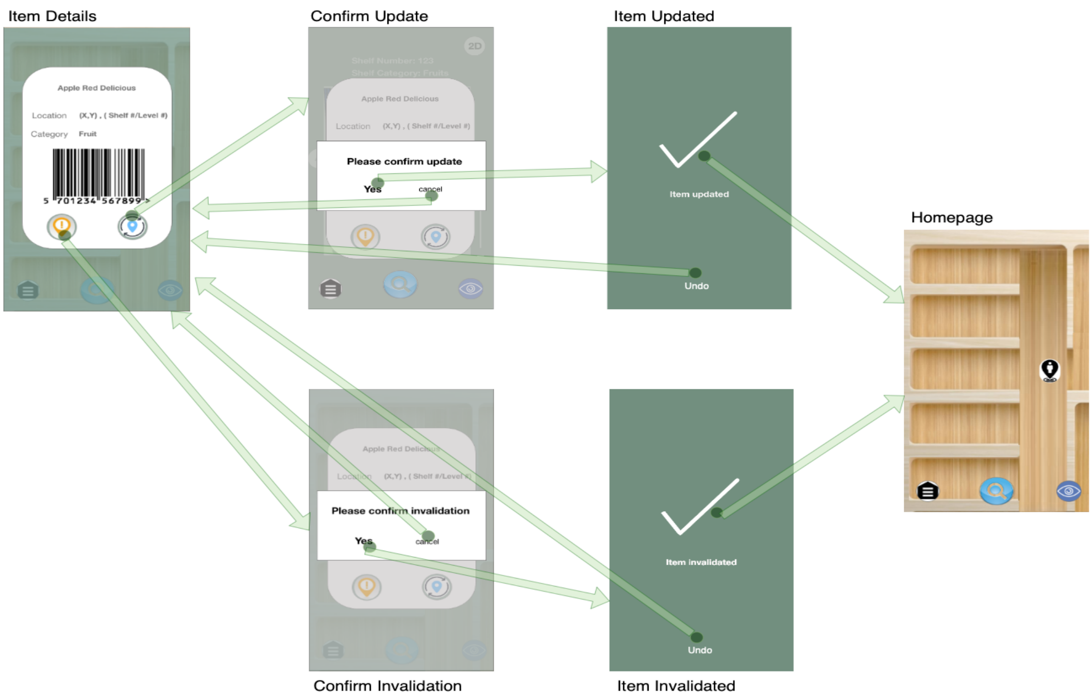


Figure 67. Third set of the wireframes views for the system's front-end mobile application.

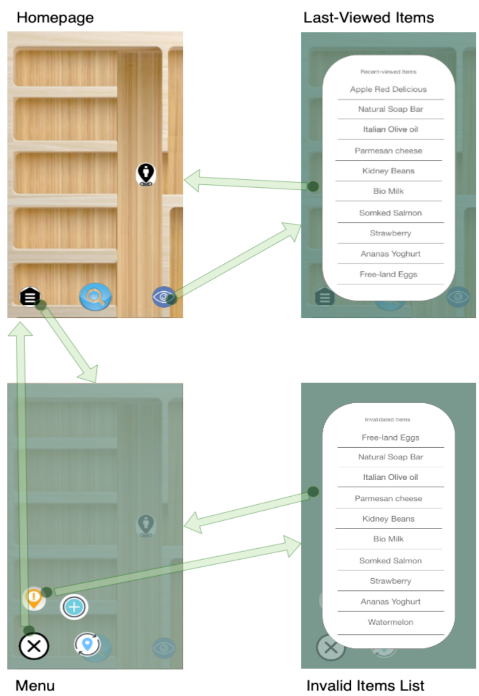


Figure 68. Fourth set of the wireframes views for the system's front-end mobile application.

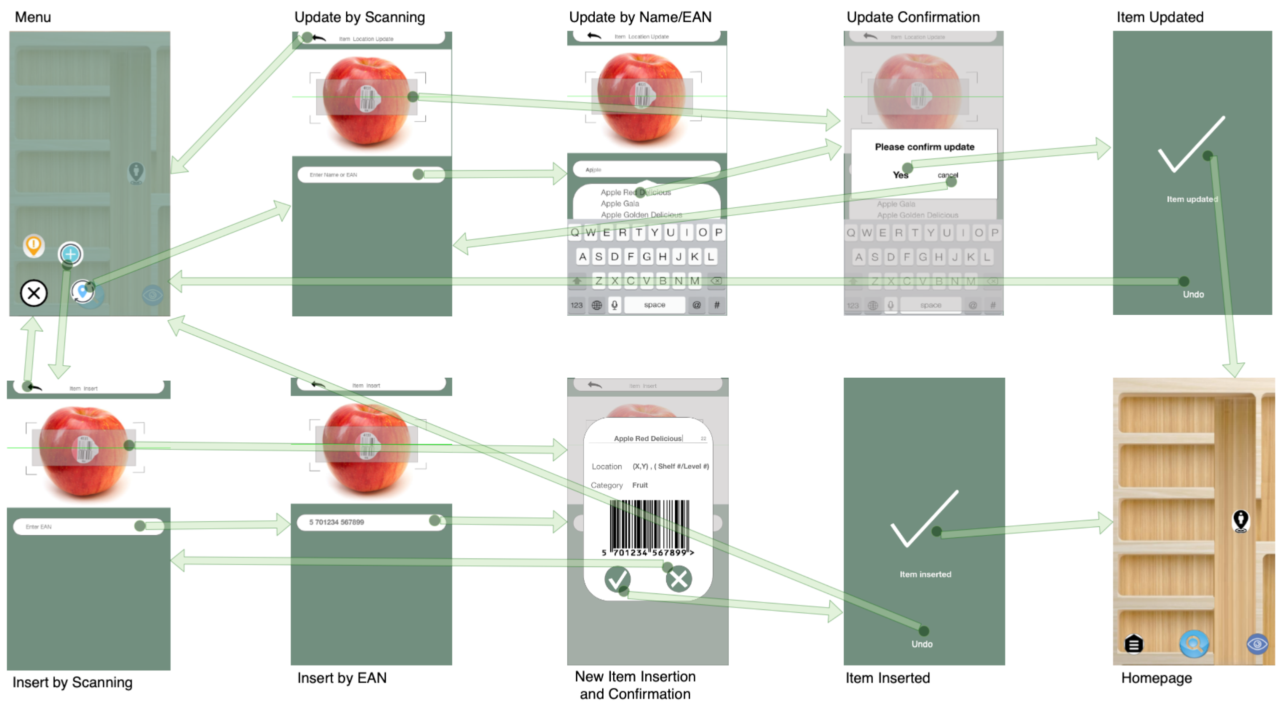


Figure 69. Fifth set of the wireframes views for the system's front-end mobile application.

2 Tables

Table .1. Evaluation of different map frameworks

Solution	Advantages	Disadvantages	Links	Evaluation
Ionic Plugin (Custom App)	1. ChartJS as drawing framework available. 2. Multi OS support with single App.	1. Plugin installation and setup is difficult. 2. Plugin might be outdated.	[18, 19]	Best to fulfill the proposed system requirements
Estimote Indoor SDK (Custom App)	1. Build a map with the estimote cloud. 2. Easy configuration, beacons can be placed anywhere in the location. 3. Location finding is integrated with beacons, no external layer needed. 4. Offline communications possible	1. SDK is only available on iOS. 2. Drawing framework is required for native OS.	[7, 8]	Good alternative
Custom mesh	Placing a mesh on the map with an algorithm -> works quite well.	Implementation is very difficult	[5]	Good alternative
Manual map on existing mesh	1. Use an existing mesh with a certain scale (1 node = 1m square) and then build map objects into the mesh 2. Easy to setup, light implementation	1. Manual changes when base map is changing 2. Can be non exact, depending on the scale	(based on the above link)	Good alternative
Google Indoor Maps	Easy integration and creation	1. Maps are undetailed 2. Using Google Universe	[12]	not suitable
MapsIndoors	1. Easy integration and creation 2. Already has location, map creation and navigation	1. You need to buy it 2. Difficult to integrate the existing location data	[22]	not suitable
AnyPlace	Already has navigation and localization	Difficult to integrate the existing location data	[1]	not suitable
OpenStreetMap	Downloadable map editor	1. Manual editing of maps with appropriate software	[23, 24, 25]	not suitable

Evaluation of different map frameworks

Table .1 – continued from the previous page

Solution	**Advantages**	**Disadvantages**	**Links**	**Evaluation**
		2. Difficult to integrate the existing location data		
IndoorAtlas	Simple usage	1. You need to buy it 2. Difficult to integrate the existing location data	[14]	not suitable
GIS	1. Using existing geo-software to load a map image and draw a navigation mesh layer on it 2. Works well, easy to setup	1. Manual changes when base map is changing 2. Difficult to integrate the existing location data	[10, 11]	not suitable
Infsoft	Great look and SDK	Difficult to integrate the existing location data	[15]	not suitable
Steerpath	Great look and SDK	Expensive	[31]	not suitable

Evaluation of different map frameworks

Table .2. Evaluation of different barcode-scanning frameworks

Name	**Easy to integrate into customized view**	**Paid subscription**	**License**	**Requirements**	**Advantages**	**Links**
Ionic Native Scanner	Only on IOS	No	MIT	NPM	Easy to implement, many tutorials	[17]
Scandit Barcode Scanner	Yes	Yes	[30]	NPM	Integration in own view, good performance	[29]
Zxing	No	No	Apache License v2.0	Maven	Many tutroials	[35]
Manatee Works Barcode Scanner SDK	No	Yes	[21]	NPM	Integration in own view, good performance	[29]
Zbar	?	No	MIT	NPM, Cordova	Good documentation	[34]
Google Mobile Vision	?	No	Apache License v2.0	Android Studio, Google Play Services SDK	Many (private) barcode scanner use this API	[13]

Table .2 – continued from the previous page

Name	Easy to integrate into customized view	Paid subscription	License	Requirements	Advantages	Links
QuaggaJS	Yes	No	MIT	NPM/Bower	MDetailed documentation, easy to use	[28]

3 Diagrams

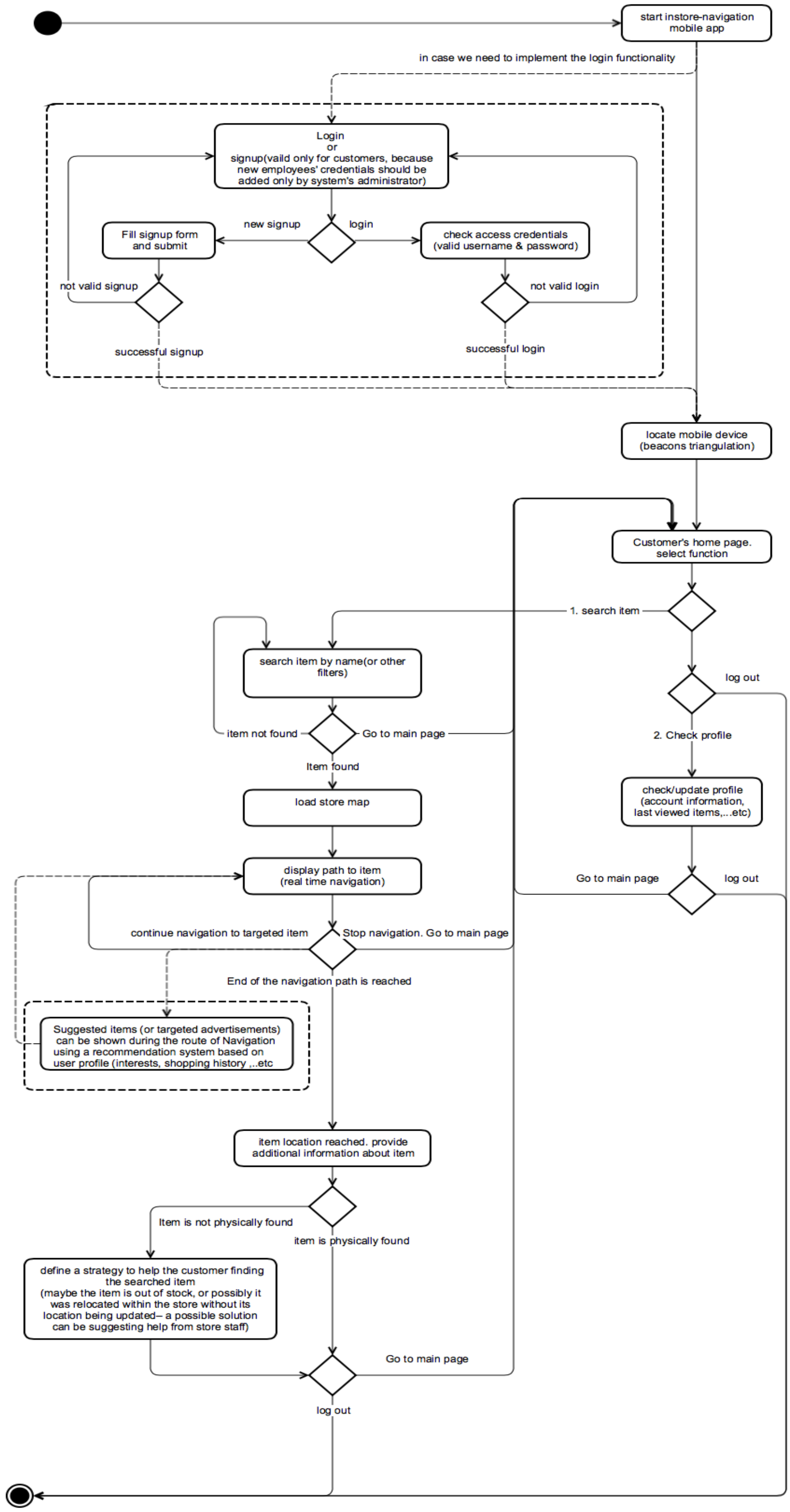


Figure 70. In-store navigation activity diagram for retail customers.

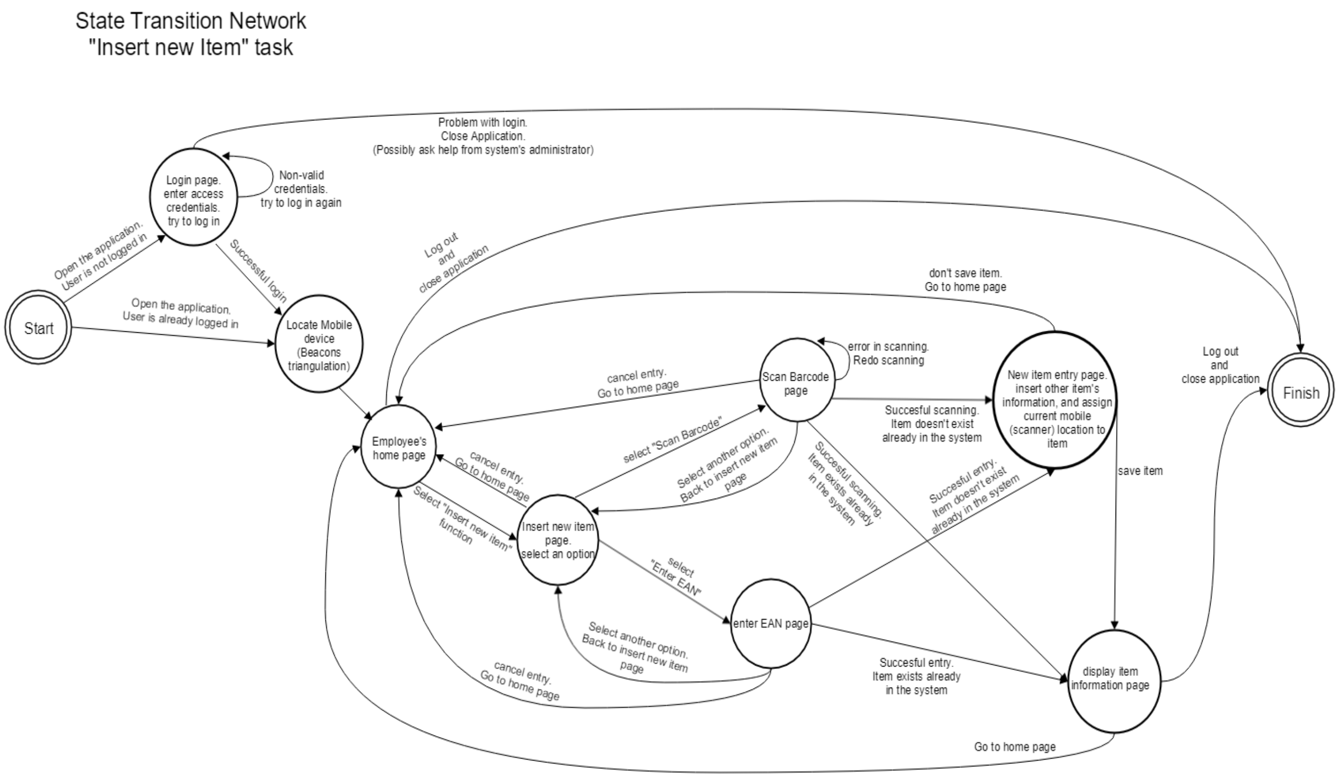


Figure 71. STN diagram of the Insert Item task.

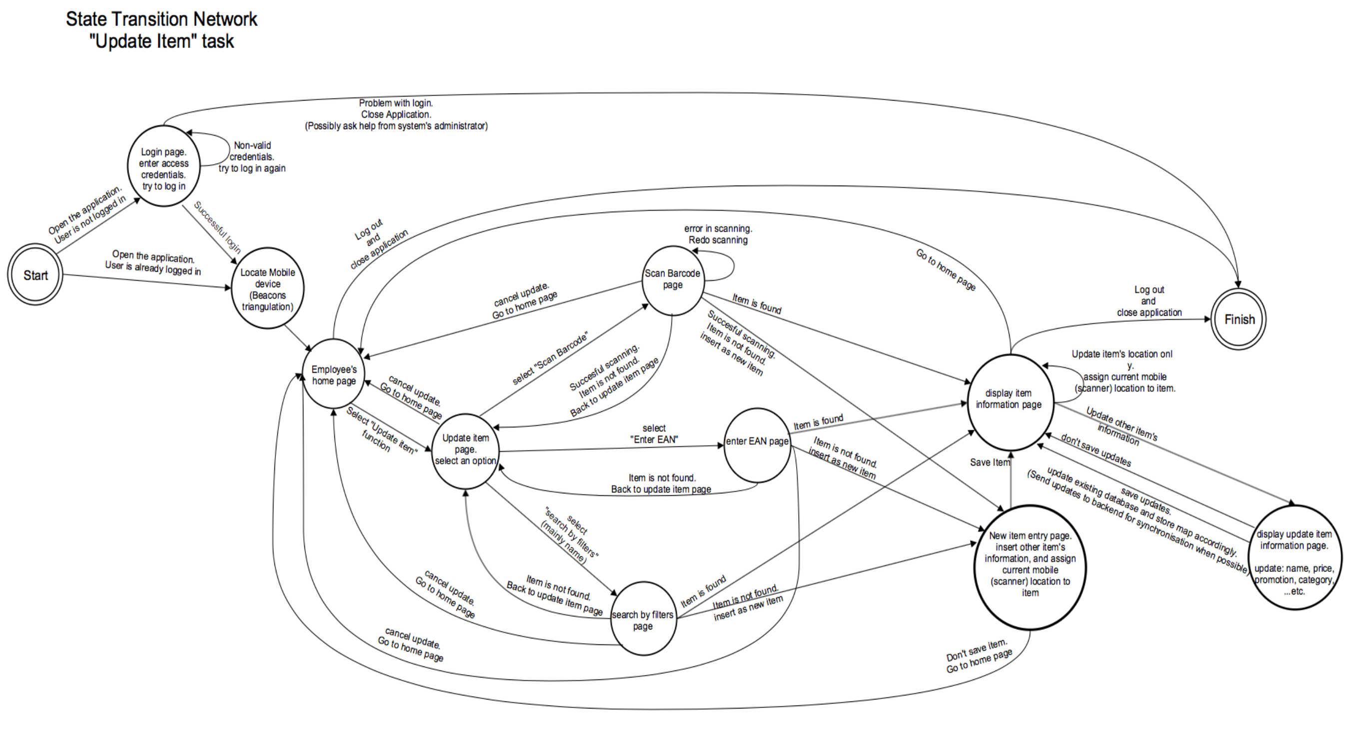


Figure 72. STN diagram of the Update Item task.

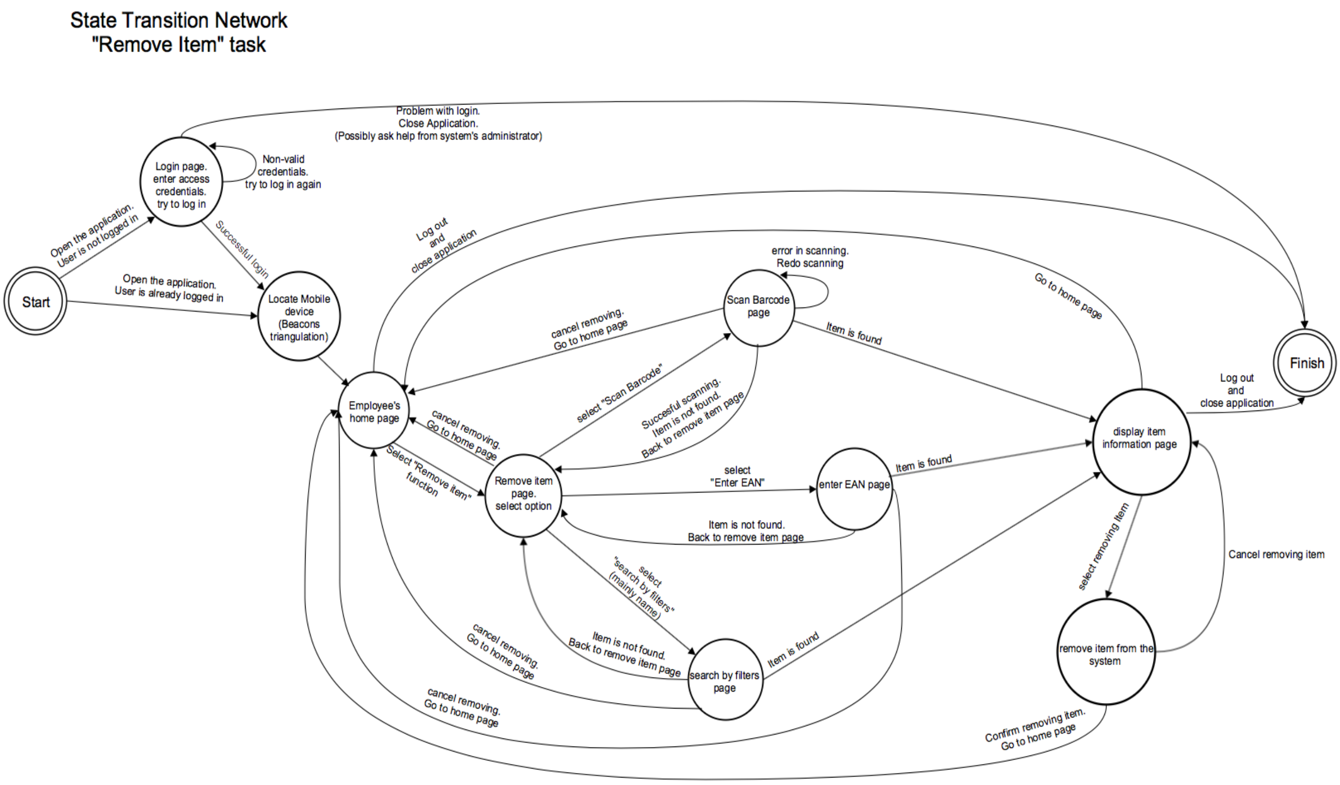


Figure 73. STN diagram of the Remove Item task.

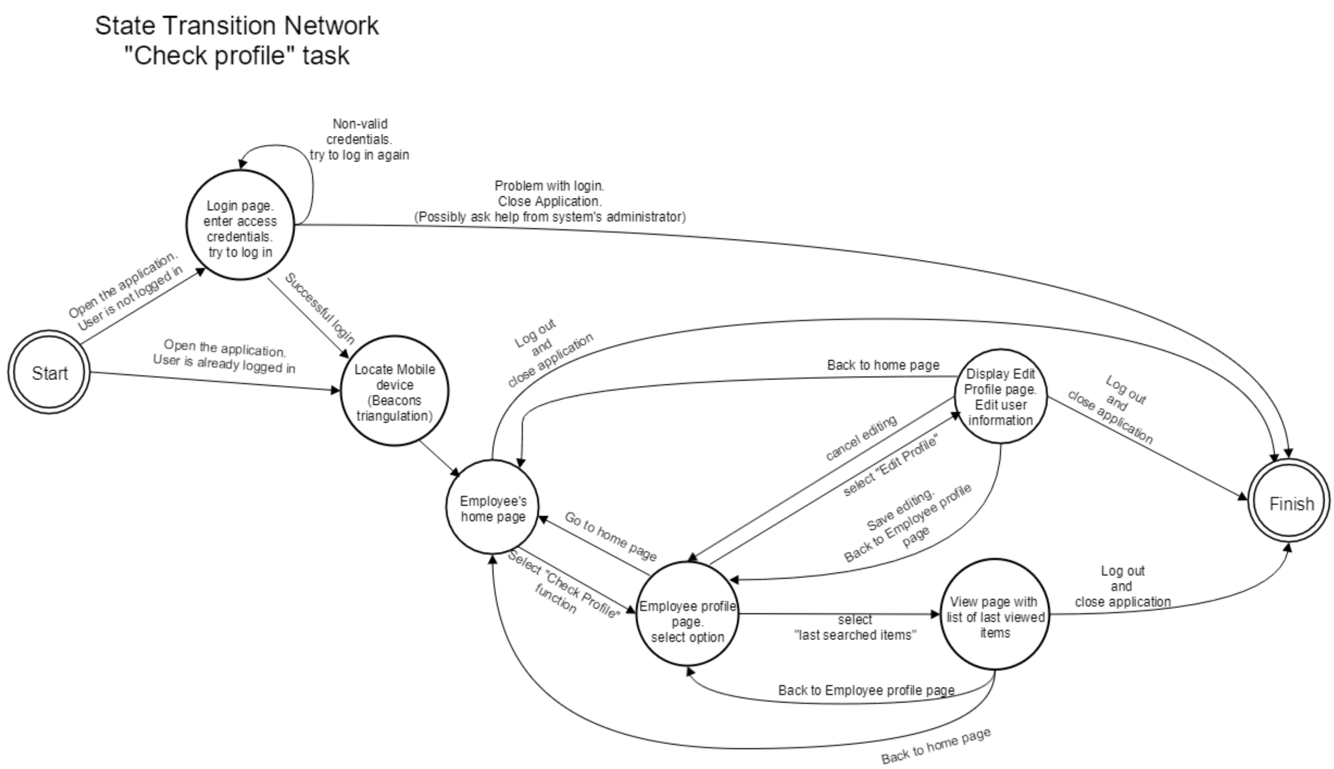


Figure 74. STN diagram of the Check Profile task.

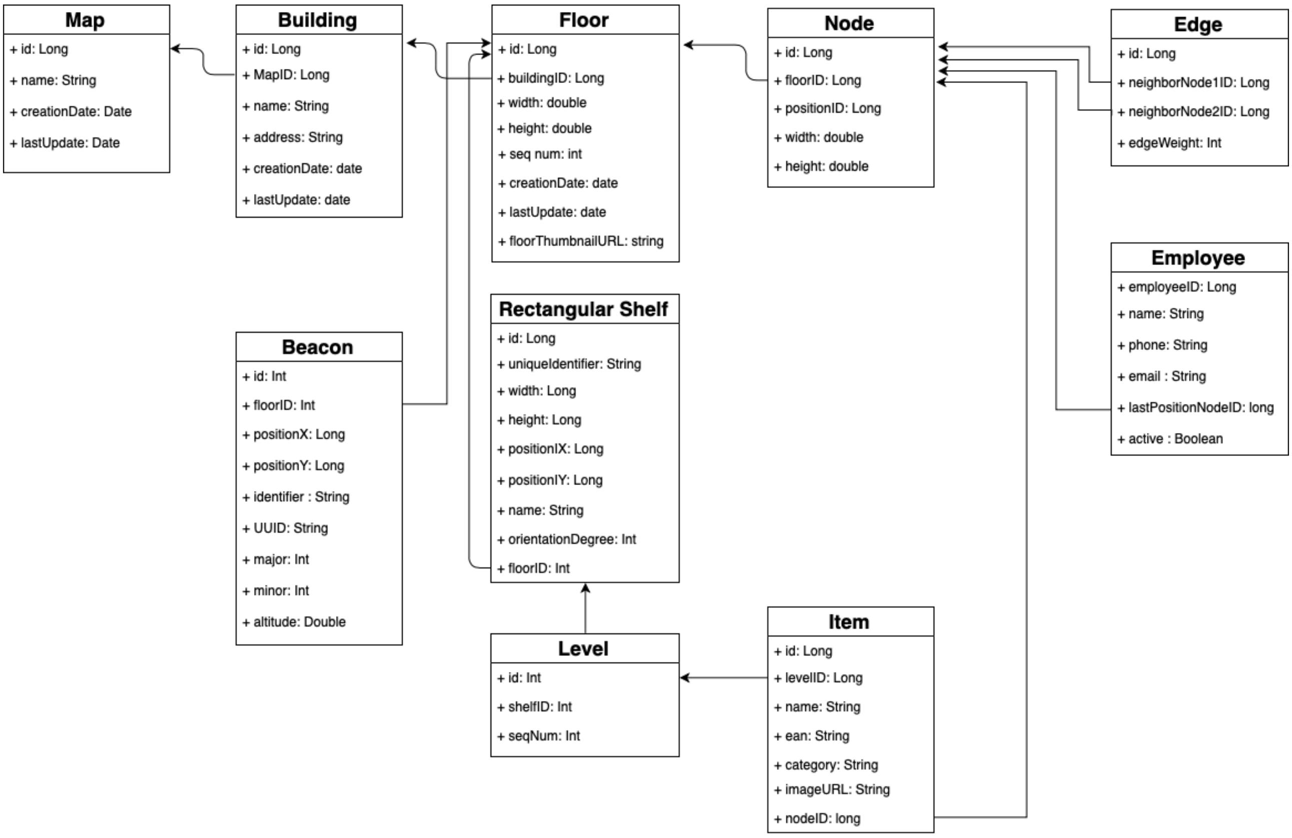


Figure 75. Possible design of the system data model.

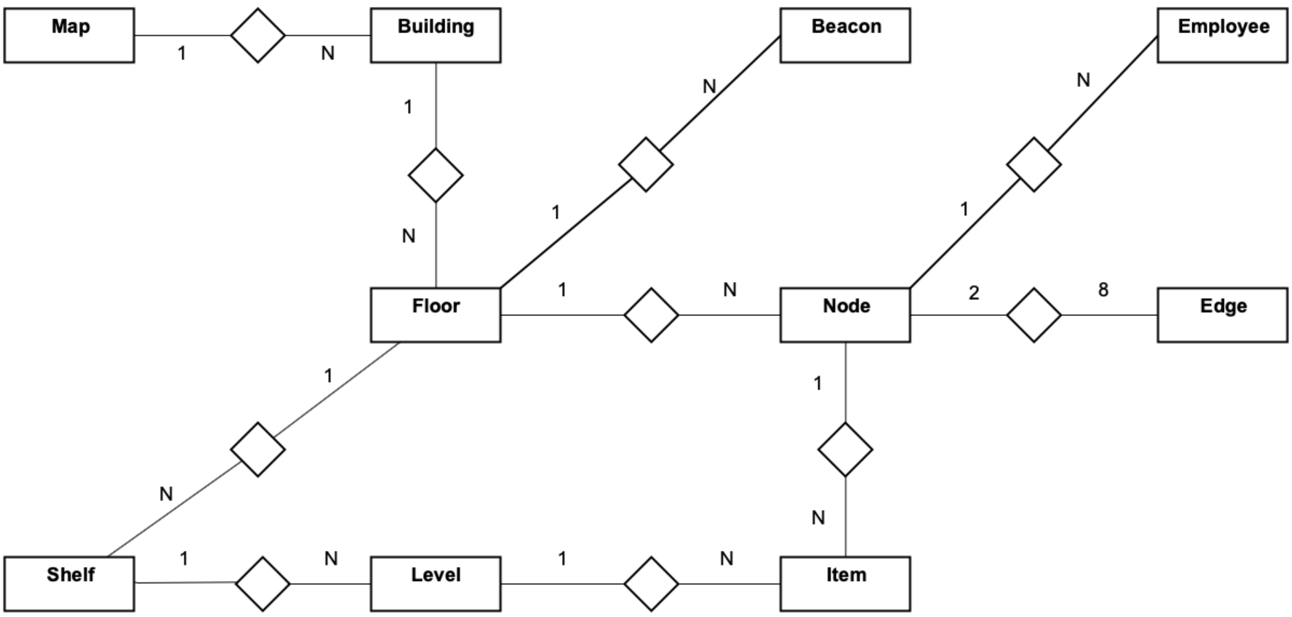


Figure 76. Entity-Relation model corresponding to the defined system data model.